Ph.D. Dissertation of Engineering

Three Essays on external economy of propulsive industry:
focuses on Korean renewable energy industry

August 2017

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Abstract

This study analyzed the characteristics of propulsive industry and externalities of propulsive industry. To examine them, this study focused on the case of the renewable energy industry of Korea as an example of a propulsive industry. Propulsive industry is defined as a set of firms or an industry which produce substitutable goods or services which significantly influence economic growth and change. The most important feature of the propulsive industry is its high externality. Externalities can be divided into pecuniary externality and technological externality. Through these externalities, the propulsive industry contributes to economic growth. Therefore, in order to investigate whether the renewable energy industry of Korea is a propulsive industry, the following three parts of the empirical analysis were conducted in this study.

The first empirical analysis examined the technological externalities of renewable energy and the resource development industry. Except technologies related to solar thermal and hydro energy, renewable energy technologies have shown a higher degree of spillover of knowledge in other fields, although it is lower than those of resource development technologies.

The second empirical analysis examined the pecuniary externalities of the renewable energy industry and the resource development industry. The output multiplier of the renewable energy industry in Korea is higher than the average of all industries, and the economic impact of the resource development industry is rather low. In particular, the output multiplier of the renewable energy industry is gradually increasing. From the value-added multiplier perspective, the renewable energy industry has a somewhat lower value-added effect than the average of all industries. Regarding employment multipliers, the renewable energy and resource development industries have a somewhat lower employment inducement effect than the average of all industries.

The third empirical analysis examined the source of value-added change from the renewable energy industry. The renewable energy industry’s contribution to the increase of national income is still low compared to other industries. The most significant effect of value added due to the diffusion of renewable energy is the change in the structure of the renewable energy industry, accounting for 61.60%. The second most contributing factor is the increase in the intensity of value added, which accounts for approximately 24.37% of the effect.

In summary, the renewable energy industry has higher technological externality and pecuniary externality. And value added from Korea's renewable energy supply is still low but is steadily increasing due to the change of its production technology. Consequently, if the renewable energy industry continues to grow, it is expected to play a role as a propulsive industry.

Keyword : Propulsive industry, Input−output analysis, Structural Decomposition Analysis, Value added, DEMATEL, Patent citation

Student Number : 2010−30256

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Chapter 1. Introduction

1.1. Research Background

The propulsive industry is defined as a set of firms which produce substitutable goods or services which significantly influence economic growth and change (Kahnert, 1988). The propulsive industry refers to industries that have a greater impact on national economic growth than other industries, as this industry has higher externalities than other industries. Externalities refer to the unintentional influence on the growth of tertiary industries due to investments in certain industries. Thus, if externalities are high, it will lead to the rapid growth of the industry as well as related industries, thereby enabling national economic growth to be achieved efficiently.

A frontier discussion of the propulsive industry and externalities can be found in the work of Perroux (1950). Perroux, in discussing economic development plans for industry development, defines three types of spaces: a planning space for planning, a business space based on economic activity, and a homogeneous space based on local homogeneities (Darwent, 1969, Lasuen 1969). There is a pole in the economic space where centrifugal force and centripetal force act, known as the growth pole. Perroux explains the economic linkages and points out that there are certain polarities in financial transactions. That is, the decision of a major conglomerate has a significant impact on the other companies associated with the conglomerate through the relationship between the customer and the supplier. Recently, the concept was changed as time went on, and it has been found that small companies, the conglomerate, can also play a role of growth pole. This is mainly because of the importance of the tertiary service industries and the importance of the integration of small firms (Park, 1997).

Scitovsky(1954) contributed greatly to embody the concept of externality. Scitovsky said that externality can be typified and divided into pecuniary externality and technological externality. The main difference between pecuniary externality and technological externality is whether externality is delivered in the market or non-market space. The pecuniary externality is transmitted through the market mechanism and affects income redistribution. Technological externality is when it affects a third party without going through the pricing mechanism and changes in the production function of industries.

Hirshman (1961) emphasizes priority and intensive investments in leading industries, which suggests that economic growth is an increasing process of linkage between leading and other industries. In other words, the growth of one industry leads to growth in other industries and the unbalanced growth of leading industries leads to the growth of the other industry. In terms of demand, the market absorbs the production growth of a specific industry with the result of cost-reduction types of innovation, new product introductions, import substitution (price decreases and new demand inducements), and on the supply side , supplies of products (input) to industry. This growth strategy offers the advantage of reducing resource use compared to the balanced growth theory.

However, if the relationship between the new industry and the traditional industry is not strong, the mechanism described above will not be established. Therefore, it is necessary to analyze the production-demand linkage structure based on the existing industrial structure and to find industries which are highly complementary to each other. Backward linkage and forward linkage are mainly used as indexes for evaluating this linkage. Backward linkage refers to the effect that the development of a certain industry induces the development of an industry that produces intermediate inputs to be put into the industry. Forward linkage refers to the effect that the development of one industry develops other industries that use the products of that industry as intermediate inputs. Hirshiman proposed that the sum of backward linkage and forward linkage be used as a composite measure of inter-industry linkages.

These growth strategy have been adopted as one of the main policy instruments for regional development since the 1960s, especially in countries that arose upon the end of World War II have taken rapid economic growth as the nation's first task. However, as the role of traditional industries has been steadily lately, efforts to find new growth engines are continuing. Therefore, finding and evaluating candidates for the new growth pole industry is once again a major challenge for governments.

One of the best cases for an empirical study is the renewable energy industry in Korea. The investment of government and local governments plays a very important role in nurturing the renewable energy industry of Korea. As the Korean government continues to provide assistance, the renewable energy industry is experiencing rapid growth. Korea's renewable energy industry sales, which stood at KRW 28 billion won in 2005, grew more than 400 times in 2015 to KRW 113.15 billion won. In 2005, there were 473 renewable energy companies, rising from only 59 in 2005. The export value of the renewable energy industry, which stood at KRW 148 billion in 2005, grew by nearly 27 times, reaching KRW 4,074 billion by 2015.

However, in order for the renewable energy industry to become a growth engine, it is necessary to consider the following aspects from a theoretical point of view. Therefore, it is necessary to examine the externalities of the renewable energy industry. There are several studies of the relationship between the existing renewable energy industry and economic growth. For example, Bhattacharya et al. (2016) analyzed the long-run output elasticity between renewable energy and economic growth in 38 countries from 1991 to 2012 and found a positive correlation between the two factors in 57% of cases.

However, the impact of investment in the industry should be considered in terms of opportunity costs. The fact that investment in industry can contribute to economic growth can be true in many industries. However, in order to become a propulsive industry, it is necessary to compare whether a certain industry, that is, the renewable energy industry in this case, has a greater impact on national economic growth than that in other industries.

This study seeks to evaluate Korea's renewable energy industry as a potential propulsive industry. Korea's energy policy can be roughly divided into domestic and overseas resource development plans (e.g., the foreign resource development basic plan, the submarine mineral resource development plan, the basic mining plan) and a renewable energy basic plan. Both of these industries have received a large amount of funding from the government, but questions remain about the effects on visible performance in each sector. In this study, the characteristics of the renewable energy industry and the impact on the national economy are analyzed in terms of the pertinent sources in light of a comparison of investment alternatives for future economic growth, with a comparison with resource development industries. In order to achieve these research goals, the empirical analysis part has the following three parts.

1) Technological externalities of the renewable energy and resource development industry

The first analysis is the analysis of patent citations for evaluating the technical externality of the renewable energy industry and the resource development industry. This study applied the DEMATEL method to quantify the impact of patent applications in the field of renewable energy and patent applications in the field of resource development to patent applications of other technology groups. This study also attempts to analyze the positions of the technology group in relation to all technological innovation relationships.

2) Pecuniary externalities of the renewable energy industry and resource development industry

Second analysis is the quantification of the economic impacts of the renewable energy industry and the resource development industry in Korea. The economic analysis tools that used here is input-output analysis. This study also summarizes recently discussed Input-Output models related an evaluation of the degree of industrial potential.

3) Sources of value-added changes from the renewable energy industry

Third analysis, the study attempts to analyze the extent of and factors contributing to the increase in national GDP in relation to the diffusion of renewable energy to other industries. In particular, in order to analyze the growth factors of GDP, value-added decomposition was used to analyze the changes in the value added. To do this, the RAS method was introduced to analyze the growth factors affecting GDP in light of supply chain fluctuations.

According to the purpose of this research, the composition of the paper is as follows. In Section 1.2, we summarize the concept of Propulsive industry, Growth Pole and Externalities, which is the background of this study. Section 1.3 briefly summarizes the current state of Korea's renewable energy industry. Chapter 2 analyzes the technological externalities of the renewable energy and resource development industry, and chapter 3 reviews the economic externalities of the renewable energy industry and resource development industry. In Chapter 4, we analyzed the source of value-added change from renewable energy industry and concluded the chapter in Chapter 5.

1.2. Renewable energy industry in Korea

The Korean government define renewable energy as three new energy and eight renewable energy. There are three types of new energy such as hydrogen energy, fuel cell, and IGCC and eight types of renewable energy such as photovoltaic energy, solar thermal energy, wind power, hydroelectric power, marine energy, geothermal energy, bio energy and waste energy. The Korean government is support for new and renewable energy by a series of deployment policies for technological development of new and renewable energy, cultivation of new and renewable energy industry, and promotion of new and renewable energy uses, such as mandatory installation of renewable energy facilities on public institutions, and lending photovoltaic energy.

Based on this support, renewable energy industry in Korea is showing rapid growth. The total sales of the new and renewable energy industry is 113,077 billion won in 2015[1]. Of the total sales of the new and renewable energy industry, the photovoltaic and wind power industry accounts for 80% of the total sales. In particular, the photovoltaic industry accounts for 83.2% of exports and 83.1% of overseas plant sales, leading to the growth of the renewable energy industry (see table 1).

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[1] It includes sales from overseas plants.

Table 1. Total sales of renewable energy industry of Korea

(unit: hundred million KRW)

	Total	Domestic consumption	Export	Overseas Production
Photovoltaic	75,637	22,975	33,892	18,770
Solar Thermal	290	290	-	-
Wind	14,571	5,123	5,639	3,809
Fuelcells	2,837	2,143	693	-
Geothermal	1,430	1,430	-	-
Water heat	29	29	-	-
Hydro	129	116	13	-
Bio	12,390	11,884	506	-
Waste	5,763	5,763	-	-
Total	113,077	49,754	40,743	22,579

Data sources: KOREA ENERGY AGENCY (2016), Industry Statistics of New & Renewable Energy 2015, pp. 19

The total number of companies in renewable energy industry of Korea is 473. The waste energy companies account for 26.8% of the total number of companies, the bio energy companies account for 26.8% of the total number of companies, and photovoltaic energy companies account for 25.8% of the total number of companies[2](see figure 1). Compared to 2014, the number of companies increased by 8.0%.

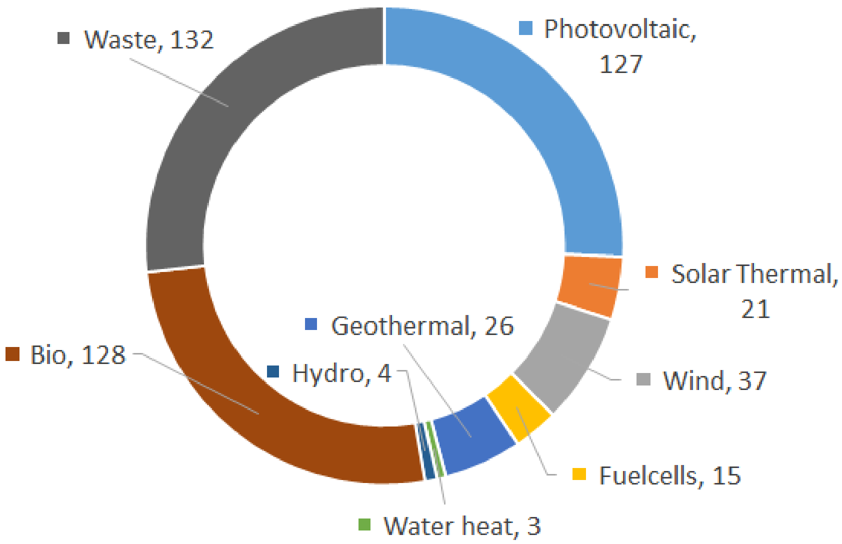

Figure 1. The number of companies in the renewable energy industry of korea

Data sources: KOREA ENERGY AGENCY (2016), Industry Statistics of New & Renewable Energy 2015, pp. 20

The number of employed in renewable energy industry is 16,177. Of the total

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[2] The total number of companies is a number excluding the duplication of companies that run two or more new and renewable energy industries. It does not match simple sum (in parentheses) of the number of enterprises by energy sources.

number of workers, the number of workers in the photovoltaic industry is the largest at 54%, followed by the number of workers in the wind power industry at 15%. Compared to 2014, the number of employment increased by 4.1%.

Table 2. The number of empolyment in the renewable energy industry of korea

	Total	Researcher	Production worker	Management
Photovoltaic	8,698	820	5,436	2,151
Solar Thermal	228	35	95	84
Wind	2,369	513	982	844
Fuel cells	802	201	423	157
Geothermal	541	104	232	166
Water heat	46	11	23	9
Hydro	83	13	32	30
Bio	1,511	122	946	387
Waste	1,899	24	1,177	430
Total	16,177	1,843	9,346	4,258

Data sources: KOREA ENERGY AGENCY (2016), Industry Statistics of New & Renewable Energy 2015, pp. 24

The total investment in renewable energy industry is 532.4 billion won in 2015. Of the total investment, the investment in the photovoltaic industry is the largest at 66.8%, followed by the investment in the waste industry at 19.3%. Compared to 2014, the investment increased by 8.5%.

In the new and renewable energy industry in Korea, the photovoltaic industry is the industry with the highest percentage of employees, sales, and investment. The photovoltaic energy industry employs 54% of the total number of new and renewable energy employees, accounting for 67% of sales and 67% of the investment, making up 26% of the total renewable energy industry followed by the second in the waste industry (27%).

In Korea, the direct investment of government and public corporations plays a more important role than other countries. Korea's renewable energy industry has been struggling to revitalize the renewable energy industry through inefficient government policies such as unreasonable regulation, reduction support policy. However, the Korean government announced the "Comprehensive Measures for New Energy Industry" in July 2016 and the "Measures to promote the deployment of New and Renewable Energy" in November 2016, and has developed various plans to support financial and investment expansion.

Accordingly, Korea's power generation companies have said that they will invest a total of 3.7 trillion won in the 17th ~ 18th period (3.4 times increase from '15 ~ '16) to the renewable energy generation business. Among them, 73.6% of the solar and wind power sector investment is in line with the government's plan to increase the proportion of photovoltaic energy and wind energy to the proportion in advanced countries (72%) by the year 2025. Also, they are planning to invest in fund products for small and medium-sized enterprises and small businesses, and are making efforts to improve investment conditions in the new and renewable energy industry. According to the Korean government, the investment amount of new and renewable energy by the six major power generation companies in Korea will be about 3.7

trillion won from 2017 to 2018, which is about 3.4 times higher than from 2015 to 2016.

Chapter 2. Technological externality of renewable energy technology and resource development technology

2.1. Introduction

The Korean government has decided to continue to invest in R&D in order to promote the commercialization of new and renewable energy. R&D investment in the renewable energy sector in Korea increased from KRW 121.9 billion in 2005 to KRW 819.3 billion in 2014, with KRW 487 billion invested in 2015. As knowledge from public R&D is a public good, aspects of inventors' ideas inevitably spill over into various firms, sectors, and technological areas, generating positive externalities (in so-called "knowledge spillovers") within an economy. Knowledge that spills across technological fields is key to advancing new technologies. Therefore, the effect of R&D in the renewable energy sector, which is supported by the government's budget, should be evaluated not only in terms of technological innovation within the sector, but also in terms of its ability to induce technological innovation in other fields.

This study examines patent data and patent citation relationships to measure the impact of technological innovation in the renewable energy sector on innovation in the field of technology at large. Generally, patent citation analysis is used for this purpose analysis. Patent citation analysis helps to evaluate the interrelationships between technologies via the analysis of citation relations between patents. In this kind of analysis, a patent citation matrix is typically used, which is a table that summarizes the mutual effects of technological innovations in different fields in terms of backward and forward citation relationships between patents. Despite the difficulty of creating such a matrix, it is a useful tool for analyzing the relationships between technological innovation in different fields of technology.

In this study, we seek to evaluate not only the technical externality of renewable energy technologies, but also the technical externality of resource development technologies. Therefore, it is necessary to analyze knowledge spillover in the renewable energy sector compared to the field of technology at large rather than merely show the relation between innovation in different sectors. This study utilizes the DEMATEL (Decision-Making Trial and Evaluation Laboratory) methodology, which was developed by the Battelle Institute in Switzerland (founded in 1971) to identify various issues in projects that seek to solve difficult and complex problems facing the world. The method is used particularly to illustrate or quantify the cause and effect structures of different problems , as well as for problem-solving, which is difficult to analyze in the usual way due to the complex and opaque relations between the factors of a given problem . Using the DEMATEL method, the degree of technical externality between renewable energy and resource development technologies can be compared, and the role of these technologies in innovation processes within the fields of science and technology at large can be analyzed.

Section 2.2 discusses R&D studies in the energy sector, Section 2.3 describes the DEMATEL method and the models applied in this study, and in Section 2.4, we discuss the study’s empirical analysis of renewable energy and resource development technologies.

2.2. Literature reviews

There are two major strands of literatures on energy technology spillovers. One is concerned with estimating technology spillovers as the effects of past knowledge stocks on current innovation in energy technologies, and the other one is concerned with investigating technology spillovers using data on patents citations, assuming that references included in patents represent a diffusion path of knowledge from one inventor to the other (Noailly & Shestalova, 2013).

Popp (2002) estimate the relationship between energy prices and energy-efficient innovations. It is one of the study that found the clear evidence for intra-technology spillover. Johnstone and Haščič (2010) also find evidence for inter-technology spillovers. They find that knowledge accumulated in storage technologies has a helpful on innovation in other clean technologies, especially in intermittent technologies.

Braun et al. (2011) find that technology innovations in solar and wind energy significantly benefits from intra-technology spillovers. Only wind energy technology seems to be affected by inter-sectoral spillovers. They gives insights into the process of knowledge spillovers, showing how these knowledge spillovers are formed.

Noailly and Smeets (2013) investigates the determinants of technical change in the power generation firms. They find that the accumulated knowledge stock in conventional energy technologies has a small positive impact on current innovation in renewable technologies for some large companies conducting both renewable energy and conventional energy innovations.

Popp and Newell (2012) use patent citations to examine the social value of energy research, in comparison to the other technologies, and conclude that energy technologies could be compared to general technologies.

Dechezleprêtre et al. (2013) investigates four technological fields which are energy production, automobiles, fuel, and lighting and finds out that clean inventions generate substantially more knowledge spillovers than non-clean inventions. Their result shows that clean patented inventions receive 43% more citations than non-clean inventions. It supports the opinion that more public support for clean invention is justified.

Noailly & Shestalova (2017) study the knowledge spillovers from renewable energy technologies to give guidance for R&D support. They find out that solar and storage technologies are significantly highly cited fields, even outside the field of power generation.

2.3 Methodology

The DEMATEL is created to analyze difficult problems which involve qualitative and interactive factor-linked aspects of social issues and allows decision makers to separate multiple factors into a cause and effect group to understand causal relationships more easily (Chen and Chean, 2012). By using the DEMATEL, decision makers can identify both direct and indirect impacts between factors, and, therefore, this method has significant implications for R&D planning over multitechnology fields, taking into account the technological convergence trend.

The traditional DEMATEL methodology started evolving in the mid-2000s. It has been combined and utilized with various methodologies to address the uncertainty of survey replies and differences in the importance of criteria. The fuzzy DEMATEL methodology, which incorporated a fuzzy logic, was designed and used to resolve the uncertainty of survey replies (Wu and Lee, 2007; Chang et al., 2011). Furthermore, the methodologies of the analytic hierarchy process (AHP) were combined with the DEMATEL for several studies to address the differences in importance among criteria (Najmi and Makui, 2010; Wu et al., 2010; Chou et al., 2012). Similarly, the methodologies of the analytic network process (ANP) were combined with the DEMATEL to resolve some issues related to the different degrees of effectiveness among criteria (Wu, 2008; Yang et al., 2008; Tseng, 2009a).

To overcome the limitations of the traditional DEMATEL model, the method has been developed in various ways. However, the subjectivity of respondents when utilizing survey responses was especially hard to overcome. According to Ko et al. (2014), patent co-classification information was used to address respondents' subjectivity. Patents commonly have both primary and supplementary class codes. Research from Breschi et al. (2003) was used in Ko et al. (2014) to measure the technology spillover from the primary class to supplementary classes, as the primary class is the focal invention area and the supplementary classes are additional invention areas (not focal, but relevant). However, this method also has some limitations: it measures technology spillovers indirectly, without confirmation through citations that show the information spillover from the relevant technology field to other technical fields. Thus, this study suggests a modified DEMATEL combined with patent citation among technology fields, which can deliver a reliable result without the evaluation of each technology field by expert advisors. In addition, this methodology can give intuitive insights into current technology spillovers in particular R&D groups by adopting directly the patent citation count among technology fields.

2.3.1 Patent citation information

Patents are objective and standard technical information that can be used to look at technology trends and technological innovation trends as well as technological innovation trends. A granted patent is a legal statement that the new technological concept embodied in the patent represents a novel and useful contribution over and above the previous state of knowledge as represented by the citations. Sometimes patents are used as a source of abundant data when it comes to providing technical and commercial information. In addition to the technical contents of the patent itself, it is possible to present trends of technology change and direction of emergence of new technology through analysis of citation information and claim range of previously filed patent, Or the skill level of the researcher (Griliches, 1990). That is to say, a citation of Patent X(Y) by Patent Y(Z) means that X(Y) represents the previously existing knowledge upon which Y(Z) builds (Jaffe *et al*., 1993), as shown in Figure 2.

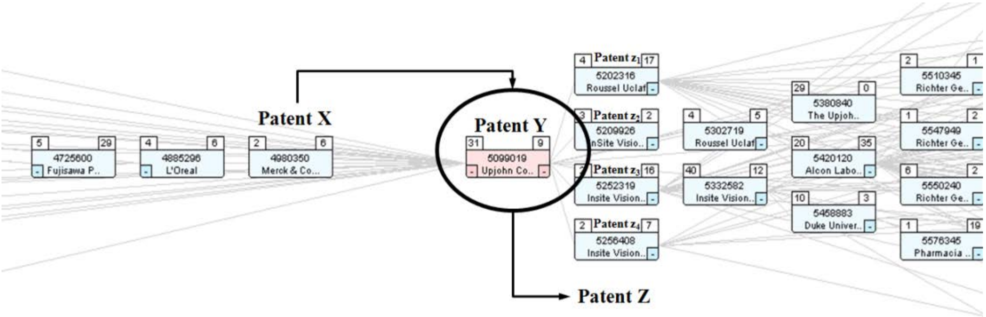

Figure 2. Diagram for forward citation and backward citation

(Source: www.wips.co.kr)

Patent Y(Z)'s citation of patent X(Y) may be indicative of knowledge/technology spillover from X(Y) to Y(Z), and citations received reflect the importance of the cited patent (Ellis et al., 1978; Carpenter et al., 1981; Carpenter and Narin, 1983; Narin and Olivastro, 1988).

Since the pioneering work by Grilliches (1990), patents have become a popular measure of innovations for the following reasons: (i) at the macro-economic level, patent activity over time is linked to the returns to R&D (Caballero and Jaffe, 1993); (ii) comprehensive data are available; (iii) technical characteristics are described in detail; (iv) the categories are well documented; and (v) it is possible to track definitions over time. After the mid-1990s, patent citation studies have expanded to include knowledge based on previous validation studies. Jaffe et al. (1993) and Jaffe and Trajtenberg (1996, 1999) presented empirical evidence on the existence of localized knowledge spillovers for the United States. Jaffe et al. (2000) suggested that aggregate patent citation flows can be used as proxies for knowledge-spillover intensity. Similarly, Jaffe et al. (2000), Fung and Chow (2002), and Hu and Jaffe (2003) showed that patent citation information is a good proxy for knowledge flow to industry.

2.3.2 DEMATEL

In a totally interdependent system, all system criteria are mutually related, directly or indirectly; thus, any interference with one of the criteria affects all others, and it is hard to identify priorities for decision making (Tzeng *et al*., 2007; Shen *et al*., 2011). To consider these complex and intertwined problematic groups, the Battelle Memorial Institute conducted a DEMATEL method project through its Geneva Research Centre (Gabus and Fontela, 1973; Fontela and Gabus, 1976). The DEMATEL aims to convert the relationship between the causes and effects of criteria into an intelligible structural model of the system (Huang *et al*., 2007; Tzeng *et al*., 2007; Liou, *et al*., 2008; Lee *et al*., 2009; Lin and Tzeng, 2009) and has been widely accepted as one of the best tools for extracting the structure of a complex problem (Fontela and Gabus, 1974; Warfield, 1976). The DEMATEL method can be summarized as follows (Wu, 2008; Tseng, 2009b; Lin and Tzeng, 2009).

Step 1: Find the average (initial direct-relation) matrix A

If we have H experts and n factors to consider in a study, experts are asked to indicate the degree to which they believe factor i affects factor j. The pair-wise comparisons between any two factors are denoted by a_{ij} and are given an integer score ranging from 0 (no influence) to 4 (very high influence). The scores assigned by experts create a n×n matrix $\boldsymbol{X}^{\boldsymbol{expert}}$=[x_{ij}^{expert}], with $1 \le k \le H$. The average matrix **A** is obtained from all expert opinions by averaging the H experts' scores as follows:

$$A = [a_{ij}] = \frac{1}{H}\sum_{k=1}^{H} x_{ij}^{k} \ . \tag{1}$$

Step 2: Calculate the normalized initial direct-relation matrix D

The normalized initial direct-relation matrix **G** is obtained through equations (2) and (3):

$$S = \max\left(\max_{1\le i\le n} \sum_{j=1}^{n} a_{ij}, \max_{1\le j\le n} \sum_{i=1}^{n} a_{ij} \right), \tag{2}$$

$$G = \frac{A}{S}\,. \tag{3}$$

$\sum_{i=1}^{n} a_{ij}$ represents the whole direct effect that factor i gives to the other factor, which is derived by summation of each row i of matrix A, as well as the summation of each column j of matrix A. $\sum_{j=1}^{n} a_{ij}$ represents the whole direct effect received by factor j. S takes the largest value between the $\max \sum_{i=1}^{n} a_{ij}$ and $\max \sum_{j=1}^{n} a_{ij}$

as the scaling factor. Matrix G is derived by dividing each element of A by s.

Step 3: Compute the total relation matrix T

A continuous decrease of the indirect effects of problems occurs along the powers of matrix **G**. The total relation matrix **T** is an n×n matrix and is defined as follows:

$$T = G + G^2 + \cdots + G^m = G(I + G + G^2 + \cdots + G^{m-1})$$

$$\mathrm{G}(I - G)^{-1}, as\ m \rightarrow \infty, \tag{4}$$

where I is the n × n identity matrix. Matrix G^m represents the power of the initial direct relation matrix that is identified as an m order indirect effect and can demonstrate the effect of mth or the effect propagated after m−1 order intermediate matrix. The entire influence matrix $T_{n \times n}$can be derived by summing up each G^m.

Step 4: Compute the total effects given and received

Define D and R as vectors representing the sum of rows and sum of columns, respectively, of the total relation matrix T as follows:

$$\mathrm{D} = \sum_{j=1}^{n} t_{ij} \tag{5}$$

$$\mathrm{R} = \sum_{i=1}^{n} t_{ij} \tag{6}$$

Let D_i be the sum of the *i*-th row in matrix $\boldsymbol{T}$. Then, D_i shows the total effects, both direct and indirect, given by factor *i* to the other factors. Let R_j denote the sum of *j*-th column in matrix $\boldsymbol{T}$. Then, R_j shows the total effects, both direct and indirect, factor *j* receives from the other factors. Thus, when $i = j$, the sum $(D_i + R_j)$ provides an index representing the total effects, both given and received, by factor *i*. In other words, $(D_i + R_j)$ shows the degree of importance (total sum of effects given and received) factor *i* plays in the system. Sometimes, it named 'Prominence'. $(D_i - R_j)$ represents the net position of the technology group in the innovation stage of the entire technology group. Sometimes, it named 'Relation'. $(D_i - R_j)$ >0 indicates the characteristic as a dispatcher, $(D_i - R_j)$ <0 indicates the characteristic as a receiver(Tamura *et al*., 2002; Tzeng *et al*., 2007, Falatoonitoosi *et al*., 2014).

However, there are two implicit preconditions in the traditional DEMATEL methodology that utilizes survey responses. First, every researcher who participates in the survey should clearly know every decision criterion. Second, survey respondents should respond objectively. However, it is hard to satisfy these conditions, especially when the decision criteria are configured for a technology field, as in this study. In other words, it may not be possible to guarantee the credibility of the analysis results according to the characteristics of the respondents.

In this research, some parts of the traditional DEMATEL model are modified to resolve the issues deriving from the two conditions described above. In this study, a technology classification established through decision criteria is provided, based on international patent classifications (IPCs) specified by the World Intellectual Property Organization (WIPO). Patent citation counts between any two IPCs provided by the U.S. Patent and Trademark Office (USPTO) were used to secure objectivity rather than depending on several experts to measure the influence degree between any two decision criteria.

Step / Model	**Set the decision criteria**	**Find the average matrix *A***	**Compute the total effects given and received**
Conventional DEMATEL model	*n* decision criteria set by researcher	Experts measure the influence degree	Eq. (2)–Eq. (6)
Modified DEMATEL model	*n* decision criteria (technology areas) set by IPCs	Patent citation counts measure the influence degree	Eq. (2)–Eq. (6)

Table 3. Comparison between conventional and modified DEMATEL models

The modified DEMATEL methodology that utilizes the number of patent citation and IPCs is shown in Table 3. In this case, if the patent citation count is composed of a matrix, there is a problem that the influence of a field having a large number of patents becomes significant. However, the number of patents is influenced not only by the innovation ability of the technical field, but also by the characteristics of the technical field. For example, in the field of applied science, the number of patents is comparatively large. In the basic science field, there is a relatively low number of patents. However, it can not be said to be an unimportant field because of the small number of patents. Therefore, in order to compensate these characteristics, we use the average number of citations divided by the total number of patent grants. Therefore, even if the number of patents is small, it can be expected that the importance of science and technology will be high if citation rate is high.

Equations (2)–(6) follow this model to calculate the total effect given and received, except for the steps needed to compose the decision criteria and the average matrix $\boldsymbol{A}$. In other words, the modified DEMATEL model used in this study has clear characteristics that make it possible to determine the decision criteria and the composition of the objective average matrix $\boldsymbol{A}$.

2.4 Empirical analysis

2.4.1 Analysis flow

Figure 2 shows the procedure of the empirical study using the modified DEMATEL method combined with patent citation information. First, the range of renewable energy and resource development technology is defined, and then IPC codes for each technology group are determined. The definition of this group of technologies is described in detail in 2.4.2 data. Second, the average number of citations for each IPC per patent was counted. The average citation count of each IPC is taken as influence level indicator because the citation count is proportionate to the number of patents in the IPC. The patent citation matrix was constructed using the number of third, average patent citations. Finally, we calculate the normalized direct-relation matrix G in the same way as in the traditional DEMATEL method to measure the total effects given and received between the IPCs. Based on matrix T, we can calculate the given and received total effects between IPCs. This modified DEMATEL model will guarantee clarity of decision criteria, objectivity of influence degrees, and reliability of the results. This analysis flow is shown in figure 3.

Step	Description
Set decision criteria	▪ Investigate the IPCs of a KIGAM-invented patent ▪ Adopt IPCs as decision criteria
Measure the influence degree between decision criteria	▪ Derive decision criteria (IPCs) from USPTO ▪ Count citations between decision criteria (IPCs) ▪ Adopt average citation count as influence degree
Find the average matrix ***A***	▪ Construct average matrix ***A*** based on Influence degree
Compute the total effects given and received	▪ Calculate the normalized initial direct-relation matrix ***D*** ▪ Compute the total relation matrix ***T*** ▪ Compute the total effects given and received

Figure. 3 Empirical analysis flow

2.4.2 Data

To conduct the DEMATEL method, the patent citation matrix must first be created. In this study, USTPO (United States Patent and Trademark Office) database was used to create a patent citation matrix. Currently, the international patent database is available at USTPO offices in the US, European Patent Office (EPO) offices in EU countries, and Patent Cooperation Treaty (PCT) in the World Patent Intellectual Property Organization (WIPO)). The reason for using the USTPO database is as follows.

First, the USTPO office is located in the United States, but the proportion of overseas applications filed during the total patent application reaches 51.1% in 2015. It also plays a leading role in industry and science and technology. Therefore, the USPTO database fully reflects the global trend.

Second, in order to analyze patent citation in reality, a common patent classification standard is needed. IPC (International Patent Classification) is a classification system that is applied internationally in order to classify patents. However, the patent offices listed above do not classify patent citation information according to this IPC code. Therefore, for the patent citation matrix, the patent citation information should be first extracted for each individual patent, and the result should be classified again according to the IPC code. This is a very labor intensive process. Therefore, it is generally possible to write a direct citation matrix only when the technology group is very small, or when the results of a project unit with a limited number of patents are analyzed. However, this study requires citation information for the entire technology group, and it is practically impossible to organize the individual information of the patent which is accumulated over 300,000 pieces every year. Therefore, a secondary database that classifies patent citation information as IPC can be usefully used by individual researchers.

A typical database available And is the Patent Data Project provided by the National Bureau of Economic Research (NBER). This database contains information on patent citations from 1976 to 2006 and has been actively used until recently in Liu et al. (2016), Le (2014) and Lamers (2012). NBER's database contains detailed information on patents, companies, individuals, and countries, but it is limited to information by 2006. Therefore, the database used in this study is based on the patent citation information established by the Department of Communication and Innovation in the Science and Technology of the University of Amsterdam. This database does not contain detailed bibliographic items, but it contains relatively up-to-date information compared to NBER's database because it contains citation information by 2011. In particular, since patents related to renewable energy have been relatively active in the 2000s, it seems more appropriate to use the information of the University of Amsterdam to investigate the characteristics of renewable energy technologies.

Therefore, the patent citation matrix of this study was created by using patent citation information of USTPO from 1976 to 2011, and each column / row consists of 430 IPC main group level and total 630 × 630 matrix. In the column direction of the matrix, the number of backward citations of patents cited in each main group is recorded, and forward citation information of each main group is cited in the row direction. The form of the patent citation matrix thus constructed is like Figure 4.

<table>
<tr><td></td><td>A01B</td><td>A01C</td><td>………</td><td>H05H</td><td>H05K</td></tr>
<tr><td>A01B</td><td></td><td colspan="4">Forward citation ---></td></tr>
<tr><td>A01C</td><td rowspan="4"><--Backward citation</td><td colspan="4" rowspan="4">Average patent citation per patent grant</td></tr>
<tr><td>………</td></tr>
<tr><td>H05H</td></tr>
<tr><td>H05K</td></tr>
</table>

Figure 4 Patent citation matrix for modified DEMATEL model

Techniques related to renewable energy are not separately classified in the IPC code, so a separate criterion is needed to define it. In this study, the scope of the patent for each new renewable energy source is referred to IPC green inventory of WIPO, and the range of the applicable patent for the renewable energy source used in this study is shown in the table. WIPO's IPC green inventory was developed by the IPC Committee of Experts in order to search for patent information relating to Environmentally Sound Technologies. Therefore, it can be said that it has a comparatively authoritative standard in the definition of the technical group. In the patent classification, we excluded the sectors related to the vehicle and application technologies with limited application in Korea.

Table 4-1. Classification of renewable energy technology based on IPC

Energy source	Technology	IPC
Photovoltaics (PV)	Devices adapted for the conversion of radiation energy into electrical energy	H01L
		H01G
		H02N
	Assemblies of a plurality of solar cells	H01L
	Silicon; single-crystal growth	C01B
		C23C
		C30B
	Regulating to the maximum power available from solar cells	G05F
	Charging batteries	H02J
	Dye-sensitised solar cells (DSSC)	H01G
		H01M
Solar Thermal	Use of solar heat	F24J
Wind energy		F03D
	Structural association of electric generator with mechanical driving motor	H02K
	Structural aspects of wind turbines	B63B
		E04H
		F03D
Fuel cells	Fuel cells	H01M
Hydro energy	Water-power plants	E02B
	Machines or engines for liquids	F03B
		F03C

Table 4-2. Classification of renewable energy technology based on IPC

Energy source	Technology	IPC
Waste	Agricultural waste	C10L
	Gasification	C10J
		F23B
		F23G
	Chemical waste	B09B
		F23G
	Industrial waste	C10L
		F23G
	Landfill gas	B09B
Biogas	Biogas	C02F
		C10L
		C12M
		C12P
Solid fuels	Solid fuels	C10L
Liquid fuels	Liquid fuels	C10L
Geothermal	Use of geothermal heat	F01K
		F24F
		F24J
		H02N
		F25B

The resource development technology to be compared can not find a classification defined separately. Resource development has a wide range of technologies ranging from resource exploration, exploitation, development and production to a wide range of targets including crude oil, natural gas, coal, metal minerals, and non-metallic minerals. However, unlike renewable energy, which is classified by technology, resource development technology can not clearly distinguish technology based on resources or light produced. Therefore, this study defined the scope of technology by referring to the list of patents filed by organizations that are responsible for comprehensive resource development. The scope of this classified technology is shown in Table 5.

Table 5-1. Classification of resource development technology based on IPC

Section	Main Group	IPC
Performing operations, Separating, Mixing	Separation	B01D
	Chemical or physical processes	B01J
	Crushing, pulverising, or disintegrating in general; milling grain	B02C
	Separating solid materials using liquids or using pneumatic tables or jigs	B03B
	Magnetic or electrostatic separation of solid materials from solid materials or fluids;	B03C
	Separating solids from solids by sieving, screening, etc.	B07B
	Disposal of solid waste	B09B
	Reclamation of contaminated soil	B09C
	Working metallic powder; manufacture of articles from metallic powder;	B22F
	Nano-structures formed by manipulation of individual atoms, molecules, etc.	B82B
Chemistry, Metallurgy	Non-metallic elements; compounds	C01B
	Compounds of the metals beryllium, magnesium, aluminium, etc.	C01F
	Compounds containing metals not covered by subclasses	C01G
	Acyclic, carbocyclic, or heterocyclic compounds containing elements	C02F
	Lime; magnesia; slag; cements;	C04B
	Materials for applications not otherwise provided for;	C09K
	Production or refining of metals pretreatment of raw materials	C22B
	Processes for the electrolytic production, recovery or refining of metals;	C25C

Table 5-2. Classification of resource development technology based on IPC

Section	Main Group	IPC
Fixed constructions	Foundations; excavations; embankments ; underground or underwater structures	E02D
	Earth or rock drilling; obtaining oil, gas, water, soluble or meltable materials or a slurry of minerals from wells	E21B
	Mining or quarrying	E21C
Physics	Measuring length, thickness or similar linear dimensions; measuring angles; measuring areas; measuring irregularities of surfaces or contours	G01B
	Measuring distances, levels or bearings; surveying; navigation; gyroscopic instruments; photogrammetry or videogrammetry	G01C
	Investigating or analysing materials by determining their chemical or physical properties	G01N
	Geophysics; gravitational measurements; detecting masses or objects; tags	G01V
Electricity	Processes or means, e.g. Batteries, for the direct conversion of chemical energy into electrical energy	H01M

2.4.3 Results

First, calculate the level of influence given (D) and the level of influence received (R) between 630 IPCs according to equation (1) - (6). The results of analyzing the renewable energy are shown in table 6 - table 7.

In the photovoltaic technology, the D value is highest (0.249) in the 'H01L' section and 'Assemblies of a plurality of solar cells'. In other words, innovation (patent) in this sector leads to the most externalities to other innovation occurrences. The R value (0.025) of the H01L sector is also the R value of eighth among all renewable energy technologies, and it can be seen that it has a low R value. In the case of solar technology, both the D value and the R value are low, and the degree of externalities to and from innovation is relatively low in the renewable energy sector.

In the wind sector, the D value (0.040) of H02K related to the 'structural association of electric generator with mechanical driving motor' technology is relatively high and the R value (0.013) of the B63B sector related to the 'structural aspects of wind turbines' .

In the fuel cell sector, it seems to have a relatively high D value and a low R value, and the D value and R value of the Hydro related technology are relatively low compared to other technologies.

Table 6. D and R of renewable energy technologies

Energy source	IPC	D		R	
		value	rank	value	rank
Photovoltaics (PV)	H01L	0.249	1	0.025	8
	H01G	0.020	24	0.026	5
	H02N	0.010	39	0.024	11
	H01L	0.249	1	0.025	8
	C01B	0.044	7	0.022	15
	C23C	0.051	4	0.026	7
	C30B	0.011	38	0.018	31
	G05F	0.032	15	0.033	2
	H02J	0.022	23	0.024	10
	H01G	0.020	24	0.026	5
	H01M	0.047	5	0.022	16
Solar Thermal	F24J	0.015	31	0.019	26
Wind energy	F03D	0.014	33	0.019	22
	H02K	0.040	9	0.022	18
	B63B	0.026	22	0.013	39
	E04H	0.034	13	0.020	20
	F03D	0.014	33	0.019	22
Fuel cells	H01M	0.047	5	0.022	16
Hydro energy	E02B	0.017	30	0.019	25
	F03B	0.013	36	0.017	33
	F03C	0.004	41	0.010	41

In the case of the waste sector, the R value (0.210) of the F23B sector related to the gasification technology is particularly high. This is because it is most affected by technology development in other sectors and can be said to be a relatively applied technology. However, for the rest of the sector, except for the B09B sector, it has a relatively low R, and the D values are all moderate. In the Biogas sector, the C02F sector has a particularly high D value (0.061), and the C12M sector has a high R value (0.031). For solid / liquid fuel related technologies, medium D value and relatively low R value (0.015) are shown. However, since demand for renewable energy in the form of soiled fuel and liquid fuel is different, more detailed research is needed. The geothermal technology is generally low in externalities, but the technology group of F25B sector has high D value (0.043) and R value (0.029).

Table 7. D and R of renewable energy technologies

Energy source	IPC	D		R	
		value	rank	value	rank
Waste	C10L	0.030	16	0.015	34
	C10J	0.012	37	0.019	21
	F23B	0.029	21	0.210	1
	F23G	0.038	10	0.019	28
	B09B	0.018	27	0.022	13
	F23G	0.038	10	0.019	28
	C10L	0.030	16	0.015	34
	F23G	0.038	10	0.019	28
	B09B	0.018	27	0.022	13
Biogas	C02F	0.061	3	0.019	24
	C10L	0.030	16	0.015	34
	C12M	0.019	26	0.031	3
	C12P	0.033	14	0.021	19
Solid fuels	C10L	0.030	16	0.015	34
Liquid fuels	C10L	0.030	16	0.015	34
Geothermal	F01K	0.017	29	0.017	32
	F24F	0.013	35	0.011	40
	F24J	0.015	31	0.019	26
	H02N	0.010	39	0.024	11
	F25B	0.043	8	0.029	4

The values of D + R (prominence) and D-R (relation) are calculated using the previously calculated D value and R value, as shown in the following table.

In the photovoltaic sector, H01L, which is related to the 'adapted to the conversion of radiation energy into electrical energy' technology and 'assemblies of a plurality of solar cells' technology, shows a high D + R value (0.274). That is, the value of Prominence is high. Also, the D-R value (0.225) is the largest, and the dispatcher's character is very strong. Also, 'Silicon; C23C sector related to the single-crystal growth technology also has a relatively high prominance value (0.077), and the D-R value is high, indicating that Dispatcher is strong. Among PV related parts, H01L, C23C, and H01M have the characteristics of Dispatcher and H01G, H02N, C30B, G05F, H02J and H01G have Receiver characteristics.

In the case of solar thermal technology, the D + R value (F24J) is high and shows weak receiver characteristics. In the case of wind technology, the D-R value (-0.005) of the F03D sector shows the characteristics of the receiver less than 0, but it is the dispatcher characteristic of the H02K, B63B and E04H sectors. Fuel cells technology has a high prominance value and a Dispatcher character. Hydro energy technology generally has a low Prominence value and a receiver characteristic of D-R <0.

Table 8. D+R and D-R of renewable energy technologies

Energy source	IPC	D+R		D-R	
		value	rank	value	rank
Photovoltaics (PV)	H01L	0.274	1	0.225	1
	H01G	0.046	19	-0.006	34
	H02N	0.033	35	-0.014	39
	H01L	0.274	1	0.225	1
	C01B	0.066	9	0.022	7
	C23C	0.077	5	0.025	4
	C30B	0.028	39	-0.007	36
	G05F	0.065	10	-0.001	23
	H02J	0.046	18	-0.001	24
	H01G	0.046	19	-0.006	34
	H01M	0.069	7	0.025	5
Solar Thermal	F24J	0.034	31	-0.004	26
Wind energy	F03D	0.034	33	-0.005	31
	H02K	0.062	11	0.019	11
	B63B	0.039	28	0.013	19
	E04H	0.054	15	0.014	18
	F03D	0.034	33	-0.005	31
Fuel cells	H01M	0.069	7	0.025	5
Hydro energy	E02B	0.036	29	-0.003	25
	F03B	0.029	38	-0.004	26
	F03C	0.014	41	-0.006	33

In the case of the F23B, which is related to the gasification technology of the waste technology, it has a high D + R value (0.240) and a very strong D-R value of -0.181. Among the sections related to the waste technology, C10l and F23G show the nature of Dispatcher and C10J, F23B and B09B show the characteristics of the receiver.

Among Biogas related technologies, the C02F sector has a high D + R value (0.081), which indicates that it is a very important technology group for diffusion of innovation, and the Dispatcher having a D-R value of 0 is also strong. Among biogas related technologies, C02F, C10L, and C12P show the characteristics of Dispatcher and C12M show characteristics of Receiver.

For the solid / liquid fuels sector, the D + R value was 0.46, indicating a moderate Prominence value and a dispatcher nature. In the Geothermal technology group, the D + R value is generally low, while the F25B part has a high D + R value (0.072), and D-R has a Dispatcher characteristic higher than zero.

Table 9. D+R and D-R of renewable energy technologies

Energy source	IPC	D+R		D-R	
		value	rank	value	rank
Waste	C10L	0.046	21	0.015	12
	C10J	0.032	37	-0.007	37
	F23B	0.240	3	-0.181	41
	F23G	0.056	12	0.019	8
	B09B	0.040	26	-0.005	29
	F23G	0.056	12	0.019	8
	C10L	0.046	21	0.015	12
	F23G	0.056	12	0.019	8
	B09B	0.040	26	-0.005	29
Biogas	C02F	0.081	4	0.042	3
	C10L	0.046	21	0.015	12
	C12M	0.049	17	-0.012	38
	C12P	0.054	16	0.012	20
Solid fuels	C10L	0.046	21	0.015	12
Liquid fuels	C10L	0.046	21	0.015	12
Geothermal	F01K	0.034	30	0.000	22
	F24F	0.024	40	0.003	21
	F24J	0.034	31	-0.004	27
	H02N	0.033	35	-0.014	39
	F25B	0.072	6	0.014	17

In order to compare the results by energy source, we integrated the technology and calculated the total D value and R value of all technologies (see the table. 10).

In order to compare the D values of renewable energy technologies, the order of Photovoltaic> Fuel cells> Biogas> Wind energy> Solid / Liquid fuels> Waste> Geothermal> Solar Thermal. Especially, it can be said that the prominance value of Photovoltaic technology is high. This means that the externalities of the technology are highest when innovation occurs in the field of photovoltaic technology and contribute to innovation in other fields. Hydro energy was the sector with the lowest externalities to spread innovation.

Conversely, when comparing the R values that represent the sectors most affected by innovation in other sectors, it is shown that the R values are in the order of Photovoltaic> Fuel cells> Geothermal> Biogas> Wind energy> Solar Thermal> Waste> Hydro energy> Solid / Liqiud fuels. The photovoltaic sector is most influenced by innovation in other sectors, emerging as a major sector, and the extenalities of technology can be considered to be a major technology. In the Geothermal sector, the degree of impact on innovation in other sectors was low, but the degree of influence from other sector innovations was high.

Table 10. Comparison of the D and R of renewable energy technologies

Energy source	D		R	
	value	rank	value	rank
Photovoltaics	0.211	1	0.025	1
Solar Thermal	0.015	9	0.019	6
Wind energy	0.033	4	0.019	5
Fuel cells	0.047	2	0.022	2
Hydro energy	0.014	10	0.018	8
Waste	0.030	7	0.018	7
Biogas	0.044	3	0.020	4
Solid fuels	0.030	5	0.015	9
Liquid fuels	0.030	5	0.015	9
Geothermal	0.024	8	0.020	3

The values of D + R (Prominence) and D-R (Relation) calculated for each renewable energy source are shown in the following table 11. Among the new renewable energy sources, the order of importance in terms of technological innovation (or knowledge externalities) was found to be order of photovoltaic> fuel cells> Biogas> Wind> Waste> Solid / Liquid fuels> Geothermal> Solar thermal> Hydro. In particular, the importance of the photovoltaic sector (0.235) is greater than that of other energy sources.

In order to compare the D-R values by circles, it was shown in order of Photovoltaic> Fuel cells> Biogas> Solid / Liquid fuels> Wind> Waste> Geothermal> Hydro> Solar. Among them, Photovoltaic, Wind, Fuel cells, Waste, Biogas, Solid / liquid fuels and Geothermal have the characteristics of Dispatcher and Solar thermal and Hydro have characteristics of Receiver. However, the solar thermal and hydro D-R values are not significantly lower than 0 (-0.004, -0.003, respectively), so the characteristics of the receiver are not large. Therefore, it can be said that renewable energy plays a role of propagating innovation in the entire science and technology.

Table 11. Comparison of the D+R and D-R of renewable energy technologies

Energy source	D+R		D-R	
	value	rank	value	rank
Photovoltaics	0.235	1	0.186	1
Solar Thermal	0.034	8	-0.004	9
Wind energy	0.052	4	0.014	5
Fuel cells	0.069	2	0.025	2
Hydro energy	0.032	9	-0.003	8
Waste	0.069	5	0.025	6
Biogas	0.064	3	0.024	3
Solid/ Liquid fuels	0.046	6	0.015	4
Geothermal	0.045	7	0.004	7

Next, the D value and R value of the resource development technology are as follows. Among the resource development technology group, the technology group with the highest D value is' Performing operations, Separating, Mixing Section', B01D (0.198). Next, the sectors with high D values were G01N (0.165), E21B (0.145), B01J (0.073) and C02F (0.061). However, it is noteworthy that the difference between the D values of the top three sectors B01D, G01N, E21B and the next sector B01J is large.

The technology group with the highest R value was E21B (0.038) in the 'Fixed constructions' section, and E21C in the same section was analyzed to have the next highest R value (0.034), followed by B03C (0.032), G01B (0.031), and B01D (0.030). Unlike the D value, which is the difference between the results of each technology group, the R value was not significantly different for each technology group. In addition, it can be inferred that the resource development technology group will play a role of propagating innovation to other technology groups as the D value is higher than the R value on average.

Table 12-1. D and R of resource development technologies

Section	IPC	D		R	
		Value	Rank	Value	Rank
Performing operations, Separating, Mixing	B01D	0.198	1	0.030	5
	B01J	0.073	4	0.019	18
	B02C	0.033	12	0.024	10
	B03B	0.006	24	0.014	23
	B03C	0.022	15	0.032	3
	B07B	0.016	19	0.018	19
	B09B	0.018	17	0.022	11
	B09C	0.004	25	0.002	26
	B22F	0.018	16	0.028	6
	B82B	0.001	26	0.005	25
Chemistry, Metallurgy	C01B	0.044	8	0.022	12
	C01F	0.009	23	0.018	20
	C01G	0.012	21	0.016	22
	C02F	0.061	5	0.019	16
	C04B	0.039	11	0.020	15
	C09K	0.039	9	0.019	17
	C22B	0.016	18	0.011	24
	C25C	0.011	22	0.016	21

Table 12-2. D and R of resource development technologies

Section	IPC	D		R	
		Value	Rank	Value	Rank
Fixed constructions	E02D	0.028	13	0.024	9
	E21B	0.145	3	0.038	1
	E21C	0.016	20	0.034	2
Physics	G01B	0.057	6	0.031	4
	G01C	0.039	10	0.021	14
	G01N	0.165	2	0.026	8
	G01V	0.027	14	0.028	7
Electricity	H01M	0.047	7	0.022	13

Based on these results, D + R (Prominence) and D-R (Relation) of resource development technology group are as follows. First, the technology group with the highest importance (D + R) among the resource development technology group was analyzed as B01D (0.228). Followed by G01N (0.191), E21B (0.184), B01J (0.092) and G01B (0.087). The difference between the top three B01D, G01N, E21B and B01J is also significant.

The D-R values were highest in B01D (0.168), followed by G01N (0.139), E21B (0.107), B01J (0.055) and C02F (0.042). These technologies are a large group of Dispatchers. In order of decreasing D-R value, E21C (-0.018), B22F (-0.011), B03C (-0.010), C01F (-0.008) and B03B (-0.007). This technology group can be regarded as a technology group which is characteristic of the receiver. However, the absolute value of the D-R value is not large compared to the dispatcher technology group, and it can be considered that it has a relatively weak receiver characteristic. In addition, it is a technology group of Dispatcher rather than a resource development technology group receiver.

Table 13-1. D+R and D-R of resource development technologies

Section	IPC	D+R		D-R	
		Value	Rank	Value	Rank
Performing operations, Separating, Mixing	B01D	0.228	1	0.168	1
	B01J	0.092	4	0.055	4
	B02C	0.057	12	0.009	12
	B03B	0.020	24	-0.007	22
	B03C	0.054	14	-0.010	24
	B07B	0.035	19	-0.002	17
	B09B	0.040	18	-0.005	20
	B09C	0.006	25	0.002	15
	B22F	0.046	17	-0.011	25
	B82B	0.006	26	-0.004	18
Chemistry, Metallurgy	C01B	0.066	8	0.022	8
	C01F	0.027	22	-0.008	23
	C01G	0.028	20	-0.004	19
	C02F	0.081	6	0.042	5
	C04B	0.059	10	0.019	10
	C09K	0.058	11	0.020	9
	C22B	0.028	21	0.005	13
	C25C	0.027	23	-0.006	21

Table 13-2. D+R and D-R of resource development technologies

Section	IPC	D		R	
		Value	Rank	Value	Rank
Fixed constructions	E02D	0.051	15	0.004	14
	E21B	0.184	3	0.107	3
	E21C	0.050	16	-0.018	26
Physics	G01B	0.087	5	0.026	6
	G01C	0.060	9	0.018	11
	G01N	0.191	2	0.139	2
	G01V	0.055	13	-0.001	16
Electricity	H01M	0.069	7	0.025	7

Based on the coefficients obtained so far, we compare the externalities of renewable energy technologies and resource development technologies. First, when comparing the resource development technology group and the renewable energy technology group, it is found that the resource development technology propagates more innovation than the renewable energy technology on average, except for the photovoltaic sector. The degree of impact of technological innovation in other fields was highest in the resource development technology group except for the photovoltaic field, and the degree of utilizing technology innovation in other fields was higher than that of all renewable energy sources. In particular, it can be said that the D value is very high, and it can be seen that it greatly contributes to the externalities of resource development technology.

These results indicate that the technological innovation of renewable energy started to increase in earnest from the mid-2000s. On the other hand, R&D of resource development technology has traditionally been invested in a large amount of capital, especially in advanced countries, this is the result. In addition, resource development technology is linked with various basic science and applied science and technology groups such as civil engineering, chemistry, and geophysics, but it can be considered that renewable energy technology contributes more to the economy. However, the D value of the solar power sector is above the resource development technology, and the R value is much lower than that of the resource development technology. Therefore, it is somewhat understandable that the technological innovation in the renewable energy field is the largest in the solar-related field.

Table 14. Comparison of the D and R of renewable energy technologies

Energy source	D		R	
	value	rank	value	rank
Resource Development	0.101	2	0.025	1
Photovoltaics	0.211	1	0.025	2
Solar Thermal	0.015	9	0.019	7
Wind energy	0.033	5	0.019	6
Fuel cells	0.047	3	0.022	2
Hydro energy	0.014	10	0.018	8
Waste	0.030	7	0.018	7
Biogas	0.044	4	0.020	5
Solid/ Liquid fuels	0.030	6	0.015	9
Geothermal	0.024	8	0.020	4

Based on these results, the D + R and D-R values of the resource development technology and the renewable energy technology are compared as follows. First, when we compare the renewable energy technology and the resource development technology, the externalities of the technology are listed in order Photovoltaic > Resource Development> Fuel cells> Biogas> Wind energy> Waste> Solid / Liquid fuels> Hydro energy. This was in a predictable order through a significant increase in the D value of Photovoltaic. Both the renewable energy technology and the resource development technology have D value rather than the R value because the characteristics of Dispatcher are stronger than the Receiver of technology innovation.

Based on the DR value, the characteristics of the technology group are characterized by Dispatcher of technological innovation, and Solar Thermal, Hydro , Hydrogen, Fuel cells, Biogas, Wind energy, Waste, Solid / Liquid fuels, Energy related technology can be classified as having characteristics as a receiver of technological innovation. However, as mentioned above, the characteristics of Solar Thermal and Hydro energy as receivers were not very strong.

Table 15. Comparison of the D+R and D-R of renewable energy technologies and resource development technologies

Energy source	D+R		D-R	
	value	rank	value	rank
Resource Development	0.126	2	0.076	2
Photovoltaics	0.235	1	0.186	1
Solar Thermal	0.034	9	-0.004	10
Wind energy	0.052	5	0.014	6
Fuel cells	0.069	3	0.025	3
Hydro energy	0.032	10	-0.003	9
Waste	0.048	6	0.012	7
Biogas	0.064	4	0.024	4
Solid/ Liquid fuels	0.046	7	0.015	5
Geothermal	0.045	8	0.004	8

2.5 Conclusion and discussion

So far, we have applied the DEMATEL method using the patent citation matrix to the renewable energy and resource development technologies and evaluated the technology externalities in terms of knowledge spillover. The results of this study are summarized as follows.

First, renewable energy and resource development technologies play a role of transferring knowledge to other fields. However, with the exception of technologies related to solar thermal and hydro energy, these two areas have shown a higher degree of spillover of knowledge in other fields. This result implies that investment in renewable energy and resource development can effectively promote technological innovation in other fields.

Second, the technology related to each energy source is listed in descending order of externalities. Photovoltaics> Resource Development> Fuel cells> Biogas> Wind energy> Waste> Solid / Liquid fuels> Geothermal> Solar Thermal. Especially, the technology group with high externalities received more influence from knowledge transfer than knowledge transfer from other technology.

Therefore, we can conclude that investment in renewable energy technologies and resource development technologies shows relatively high technology externalities through knowledge spillover. These results are convincing conclusions, especially considering that technological development in the photovoltaic sector in Korea as well as in the global market is driving technological innovation in renewable energy technologies.

In addition to verifying the technological externalities of renewable energy and resource development technologies, the contribution and utilization of this analysis can be summarized as follows. First, we can contribute to efficient R&D investment planning by comparing knowledge spillover by element technology group of new renewable energy and resource development technology. As mentioned earlier, R&D with public investment should involve technological externalities. Therefore, the results of this study can be utilized in constructing the technology investment portfolio.

Secondly, this study adopts a modified DEMATEL design to eliminate the bias arising from the subjective answers of respondents and allows researchers to deduce objective results. Generally, the crucial starting point of the DEMATEL method based on peer review is a clear awareness of decision criteria within a panel, and each panel determines their influence degree subjectively. However, this study tries to enhance the objectiveness of the DEMATEL method by adopting IPCs as decision criteria and patent citation count as an indicator of their relative influence degree.

However, even though we claimed that patent citation data is a major indicator of technology spillover, there are some limitations to the modified DEMATEL method based on patent citation data. First, quantitative analysis based on past data assumes that the future data trend is expected to be similar to past data trend. In other words, if a shock occurs and it is large enough to cause changes to the economy, politics, or science, the benefits of quantitative data are impeded. Second, patent databases are not always up to date, especially for technology fields undergoing very rapid changes. However, these limitations are inevitable in quantitative analysis, and, sometimes, complementing it with other analysis using text mining, journal citation, or qualitative analysis could be helpful. Third, there is a problem that the patented citation is used for the analysis of the same size when using the counted number of patent citations. The significance of the patent may be different depending on the importance of the technology. Since the number of simple counts is calculated, the less important technologies are calculated to have the same level of significance as other technologies, so the data may be distorted somewhat. If a standard-essential patent is used as data, only a standard patent essential for the implementation of the standard technology is targeted, so that a technology having a low technical importance can be excluded. Standard-essential patents are patents included in the standards established by standardization organizations such as ISO, IEC, ITU, ETSI, etc., and only standard patents essential for standard technology are applied when using standard-essential patents. However, the standard-essential patent can not be used for citation information yet, and it is considered that it is difficult to use it for direct analysis because it is fewer than the general patent. Therefore, it can be used as a supplementary reference level.

Chapter 3. Pecuniary externality of the renewable energy industry and resource development industry

3.1. Introduction

From 2010 to 2015, the annual growth rate of new and renewable energy generation was 7–9%, with an accumulated installation of 1,859 GW, and an additional installation of 148 GW in 2015. Renewable energy generation doubled in 2015 compared to 930 GW in 2005 (REN21, 2007, 2012, 2016). The development in 2015 was considered p roof that the growth of renewable energy could continue at a rapid pace into the future, as such growth occurred even when the price of oil was very low. However, despite such growth, there has been concern that the effort to mitigate climate change will shrink and that the production of fossil fuels will expand due to policies implemented by the current president of the United States. Indeed, the supply of renewable energy could diminish if government support for renewable energy is reduced in the US and the clean power plan (CPP) is abolished. Based on the policy of the Obama administration, however, the Energy Information Administration (EIA) (2016) predicted that the supply of renewable energy would be 1,300 TWh in 2040, and roughly 1,200 TWh even if the CPP was to be abolished. Therefore, it can be argued that the expansion of the renewable energy market is possible regardless of policy support from the government as the price of renewable energy becomes more competitive with fossil fuels.

Researchers in academia have made similar predictions. For example, Bhattacharya et al. (2015) analyzed the long-run output elasticity between renewable energy consumption and economic growth within 38 countries from 1991 to 2012 and found a positive correlation between the two factors in 57% of the countries. The finding shows that renewable energy can not only serve as a means to respond to climate change, but that it can also contribute to economic growth. However, confirming the economic feasibility of the renewable energy industry requires further investigation into whether or not investment in the renewable energy industry has a comparative advantage over investment in other industries. Even though certain energy sources, such as wind and photovoltaic energy, have begun to have economic feasibility compared to fossil fuels, the expansion of renewable energy still depends on governmental policy support in many countries. Given that the goal of industrial policy-making is to maximize the utility of limited resources by efficiently allocating them, it is necessary to confirm the comparative advantage of investment in the renewable energy industry over investment in other industries in terms of pecuniary externalities.

In this study, we examined whether investment in the renewable energy industry is useful in terms of fostering new industries in the energy sector compared to the resource development industry, which has a complementary relationship with the former.

3.2. Literature reviews

Research on the economic effect of the renewable energy industry has substantially increased as the renewable energy industry has been growing since the 2000s. This research can be broadly divided into four categories:(1) research using basic indices (e.g., number of employees per renewable energy system MW); (2) research using analysis on the direct and indirect effects of industry on the economy; (3) research using the top-down method with econometric models; and (4) hybrid research of the methods above Markaki et al.(2013). Among such methods, analysis adopted for the present study is useful as it allows the effect of the entire national economy on the changes in a specific industrial sector to be analyzed Miller and Blair (2009).

Císcar-Martínez (1997) analyzed the effects of a photovoltaic, wind, and biomass power generation system installation project on employment, income, and value added in Turkey, Tunisia, and Morocco. The results showed that although the photovoltaic and wind power generation sector created 60% of the total employment of the renewable energy sector in terms of employment inducement, an improvement is needed in terms of import inducement since the import cost of solar panels was 47% of the total project cost. In terms of value-added inducement, the value added was mainly generated in the renewable energy plants sector rather than in other industries.

Itoh and Nakata (2004) discussed the positive and negative economic impacts caused by the installation of the renewable energy facilities in rural areas of Japan, and it was found that the cost of the energy system was reduced by $4.3 million but a $2.7 million loss occurred in gas and electricity.

Torgerson et al. (2006) analyzed the economic impacts of wind power energy development in Umatilla County, Oregon, United States. The effect of wind farm development was analyzed by using IMPLAN (Impact Model for Planning) based onanalysis and it was found that the induced effect was about $40 million and more than 90% of the industry in the entire region was affected by the development of wind power energy.

Caldéset al. (2009) analyzed the economic impacts caused by the deployment of solar power generation by using analysis in Spain and found that Spain would create 108,992 jobs per year by 2010 investment in solar energy. In addition, Coon et al. (2012) analyzed the economic impact and the changes in the renewable energy industry in North Dakota using analysis from 2002 to 2011 and estimated $1.2 billion production inducement for the total investment of $326 million in 2011.

Markaki et al. (2013) analyzed the impact of investment in renewable energy according to the scenarios involving the planned investment amount for 2010–2020 in Greece and calculated a €9.4 billion annual production increase for a €47.9 billion investment and 108,000 new jobs created.

Research has focused on the employment-inducement effect by investment in renewable energy with an interest in the renewable energy industry as a means to overcome the crisis of the recent global economic contraction and employment decline. Hienuki et al. (2013) analyzed the employment effect by investment in geothermal power generation using analysis and found that the employment induced during the entire life cycle of the geothermal energy system was 0.81 person/GWh.

Ortega et al. (2015) found that the employment-inducement effect due to renewable energy per GW is on a declining trend as the renewable energy technology develops and that 548,019 jobs were created because of renewable energy in the 28 EU countries in 2012.

Garrett-Peltier (2017) used input-output analysis to compare the employment impacts of the renewable energy sector with the employment impacts of the fossil fuels industry. The results of this study are summarized as follows: (1) A total of nine studies were compared with the results of the study (Garrett-Peltier (2011), Pollin et al (2015), Tegen et al. (2013), IRENA (2012a, 2012b), Black and Veatch , DOE (2013), and Larsen et al. (2012). According to the results of these studies, the magnitude of the employment inducement effect was the order of Hydro (6.90)> Geothermal (5.43)> Wind, Solar (4.74)> Bioenergy (3.82).

A review of these studies indicates that the ripple effect of the renewable energy industry is positively evaluated in most countries. That is, the renewable energy industry has a significant effect on driving economic growth and is found to contribute to job creation. However, as seen in Císcar-Martínez (1997), it appears necessary to review the import inducement, since it could be significant if the infrastructure of related industries is insufficient.

In case of Korea, Kim (2004), Korea Energy Economics Institute (2004), Ministry of Knowledge Economy (2009), Jung et al. (2009), Lee (2010), Hwang(2010) and Jin (2011), Lee et al. (2011) analyzed the economic impacts of the renewable energy industry using Input-Output analysis.

Kim (2004) analyzed the employment effects of the wind power industry and solar photovoltaic industry using industry - related analysis. And, the classification and investment structure of the wind power industry is visited by major companies that have installed wind turbines in Jeju Island and Saemangeum region, and they have direct consultation with the personnel, telephone consultation with the representative department of Korea Standard Industry Classification. Using the investment structure thus obtained, the number of labor and labor inducement coefficients of the wind industry were obtained, and the employment effect of the wind industry was obtained by using the learning rate of the wind industry and the forecast of the generation rate.

In the Energy Economy Research Institute (2004), it is reported that the technological development of renewable energy sources leads to the improvement of the element technology and the demand for the element technology, and the expansion of the production volume of the renewable energy equipment industry. The economic feasibility of technology development by renewable energy source was analyzed. The technology of each renewable energy source and its investment structure were estimated by one to one interview with experts. As a result of analyzing the comprehensive economic feasibility of the renewable energy technology development project based on the profit margin law, the energy source with the highest return on investment in terms of value added was bio energy, followed by waste energy and solar energy. The reason for this result is interpreted that bioenergy and waste energy have advantages such as technology is already commercialized, and a large amount of output can be obtained even with a small amount of R&D funds.

Jung et al.(2008) conducted surveys of companies that generate sales, and analyzed the investment structure of photovoltaic, wind, fuel-cell energy industry.

Jung et al.(2008) also used this to estimate the investment structure of the renewable energy facilities industry in 2020.

Jin & Kim (2011) analyzed the data of 1,451 companies that are supported by electricity generation in 2010, and analyzed the solar power, wind power, small hydro power, fuel cell, LFG (Landfill gas), biogas, biomass, RDF Derived Fuel (R&D), which is one of the new renewable energy sources.

Lee et al. (2011) estimated the number of manpower needed for each renewable energy source by applying the industry association analysis and the stock approach of the US Bureau of Labor Statistics (BLS). Thus, these studies provide policy implications for growth strategies based on the characteristics of renewable energy sources, by comparing characteristics of renewable energy sources.

Hong et al.(2012), Kwon et al. (2016),also analysed the ripple effects of renewables, but analysed the new renewable energy industry as a whole without dividing it by energy. Thus, the significance of the national level of the new renewable energy industry is explained, but the implications for new renewable energy sources and future growth direction are somewhat insufficient.

The studies listed above suggest that the outlook for the new renewable energy industry is positively optimistic and that the impact on the Korean economy will be huge. However, they does not provide the necessary implications for the new renewable energy industry in the present policy environment, as it does not comprehensively depict the characteristics of the new renewable energy industry, the effectiveness of government investments, and the comparative advantage of economic impacts of economic energy to other industries.

3.3. Methodology

3.3.1. Input-Output Analysis

Input-Output analysis can be defined as a quantitative analysis of the interrelationships between production and consumption, ie, as a buyer of other goods, as a consumer of production factors, and as a seller of goods to other consumers. In a typical economic analysis, producers seem to play the two roles of buyer of the factor and seller of the product(BOK, 2007). Why do we need to analyze the interrelationships between the economic sectors? This is because it is possible to grasp what is difficult to explain with conventional national income analysis or partial equilibrium analysis through sectoral industrial relations.

In general, the cycle of the national economy can be grasped in two ways: income circulation and inter-industry cycle. Income circulation refers to the process of returning from the generation of income through distribution and disposal to the next production process. Inter-industry circulation refers to the transactions of goods and services between the production sectors and is excluded from the national income account, but it is a very important part to understand the inter-industry linkages. Input-output analysis analyzes the production structure behind such incomes, while the usual economic analysis analyzes the economic activity of the entire national economy with respect to income circulation. In other words, it seeks to capture the technological interdependence between industrial sectors at the stage of the industry that constitutes the national economy, and to analyze the impacts of the end-demand on the national economy by applying final demand as exogenous variables (BOK, 2007)

For analyzing the impact on the national economy or establishing policies, it is necessary to examine the interrelationships among industries in structural aspects by dividing the national economy into industrial sectors. In this respect, it is very important to understand how the changes in the final demand for an industry's products will affect their production activities. While the analysis of national income using econometric model can indicate the level of activity of the entire national economy, it is not sufficient to analyze the relationship in the economic structural aspect. For example, if you are trying to implement a policy to increase national income by increasing demand, the usual national income analysis shows no difference in the effect of spillover effects, either by increasing demand for housing or by increasing demand for passenger cars none. However, as demand for automobiles increases, demand for precision machinery and machinery will increase, and demand for cement and wood will increase as demand for housing increases. As a result, the content of employment and the amount of incomes to be incurred will vary depending on whether the production is directly or indirectly increased. Therefore, if there is a difference in economic ripple effect according to the content of demand, it is reasonable to distinguish it from the policy decision process.

Using input-output analysis, it analyzes the structure of production technology of each industry, the direct or indirect relationship between industry and the structure of final demand, and analyzes the effect of specific policy or industrial sector on the national economy. It can be divided into industrial sectors. For example, when the demand for the housing sector is increased, the input-output table can be used to determine how much the value added and employment will be different in each industry sector. Therefore, it can be used as an analytical tool for establishing and forecasting of economic plan and setting up direction of industrial structure policy.

3.3.1.1 The concept of Input-Output analysis

In general, systematic research in economics has been started since Adam Smith. Since the publication of Adam Smith's Wealth of Nations, which is often referred to as the beginning of modern economics, economics has evolved in many ways, and with the advancement of economics, economics has become a subject of interest. The classical school represented by Adam Smith was the main subject of analysis of the macroeconomics which explains the principle of deciding the nation's income, employment, prices etc. On the other hand, Marshall focused on microeconomics which explains the principles of decision of supply and demand of goods, focusing on households and corporations among economists. In simple terms, classical schools analyzed the economy as a whole, and in the pre-school system, the economic flows were analyzed by individual economic entities. However, the economic analysis should cover both the whole and the sector, but not the entire economy.

Since the 1930s, economists such as JM Keynes have focused on the balance, imbalance, and the economy as a whole, including the elements of the partial equilibrium analysis of microeconomics in the field of macroeconomics. I did it. This analysis is concerned with how economic variables are related to one another and how one variable affects other variables while targeting the whole economy. However, this analysis has not paid much attention to the correlation and interactions between the economic structure and the economic agents or industries that make up the economy.

A systematic study of inter-relations between economic agents can be found in F. Quesnay's Economic Table and the rationale is based on L. Walras and V. Pareto's Balance model. Walras's theory of general equilibrium is basically a theory that explains the determination of the price and the quantity of supply, assuming that all economic sectors in the market economy are closely related to each other, so that the balance between demand and supply of these sectors is made at the same time.

The US government first officially utilizes the Input-Output table in 1947, followed by the Input-Output table in 1948 in the United Kingdom and 1951 in Japan. In addition, the United Nations Statistics Bureau also provided input-output table creation instructions called "Problems of Input-Output Tables and Analysis" in 1966. Input-output tables have been widely spread worldwide. It is widely used for analysis of economic structure, economic forecasting and policy formulation.

Input-Output analysis is a quantitative analysis of the interrelationships between production and consumption, that is, as a buyer of other goods, as a consumer of production factors, and as a seller of goods to other consumers (industrial or business) Research, and research. In a typical economic analysis, producers seem to play the two roles of the buyer of the factor and the seller of the product, but in addition to these two roles in the Input-Output analysis, it is necessary to purchase products from other companies or industries, As well as a role to sell. Why do we need to analyze the interconnections between the economic sectors? This is because it is possible to grasp what is difficult to explain with conventional national income analysis or partial equilibrium analysis through sectoral industrial relations.

In general, the cycle of the national economy can be grasped in two ways: the circulation of income and the interindustry circulation. Income circulation refers to the process of returning from the generation of income through distribution and disposal to the next production process. Inter-industry circulation refers to the transactions of goods and services between the production sectors and is excluded from the national income account, but it is a very important part to understand the inter-industry linkages. Input-output analysis analyzes the production structure behind such incomes, while the usual economic analysis analyzes the economic activity of the entire national economy with respect to income circulation. In other words, it seeks to capture the technological interdependence between the industrial sectors at the stage of the industry that constitutes the national economy and to analyze the ripple effect of the end-demand on the national economy by applying the final demand as an exogenous variable (Bank of Korea, 2007)

In general, the econometric model using the simultaneous equations or the vector autoregressive model (VAR) is used as a method for analyzing the economic effect besides the input-output analysis. However, for a more in-depth economic analysis such as analyzing the ripple effects of the national economy or establishing future economic forecasts and policies, it is necessary to examine the interrelationships among industries in structural aspects by dividing the national economy into industrial sectors. In this respect, it is very important to understand how the changes in the final demand for an industry's products affect the production activities of each industry. An analysis of the national income using a metric model shows the level of activity of the entire national economy Even if there is a number, it is not enough to analyze the connection in the economic structural aspect.

For example, if someone is trying to implement a policy to increase national income by increasing demand, the usual national income analysis shows no difference in the effect of spillover effects, either by increasing demand for housing or by increasing demand for passenger cars none. However, as demand for automobiles increases, demand for precision machinery and machinery will increase, and demand for cement and wood will increase as demand for housing increases. This leads to changes in the direct and indirect sectors where the production is increasing, the amount of employment and the amount of income generated. Therefore, if there is a difference in economic impact according to the content of demand, it is reasonable to distinguish it from the policy decision process.

The input-output analysis analyzes the production technology structure of each industry, the direct or indirect relationship between them, and the composition of the final demand. Therefore, the effect of the implementation of specific policies or the industrial sector on the national economy, can be analyzed separately. For example, when the demand for the housing sector is increased, the input-output table can be used to determine how much the value added and employment will be different in each industry sector. Therefore, it can be used as an analytical tool for establishing and forecasting of economic plan and setting up direction of industrial structure policy. In particular, in countries where rapid changes in terms of production technology or industrial structure, such as Korea, are complementary, macroeconomic analysis and input-output analysis are more important. For this reason, Korea introduced the input-output table of 1960 for the first time in 1964 and started to use the input-output table for the first time in 1964.

Economic correlations and interactions can not be missed in order to analyze the contemporary economic problems in which economic agents are increasingly correlated and no one goods or industry moves independently of other activities or industries. Therefore, in the modern age, there is an increasing need for economic analysis that explains the actual economic phenomenon in more detail, taking into account such interrelationships. Therefore, the development of Input-Output analysis reflects the necessity of this period. In addition, the development of computers greatly reduces the time and effort required for computation, which has contributed greatly to the ease of use of input-output tables in today's economic analysis.

3.3.1.2 Multiplier Analysis

1) Input-output table

Each industry sector that constitutes the national economy trades raw materials and intermediate goods, and combines primary input factors such as labor and capital to produce new goods or services and sells them to other industrial sectors or final consumers. A table that summarizes these transaction relationships in a matrix form is called an input-output table. In other words, the Input-Output table is a statistical table in which all transactions occurring during the production and disposal of goods and services within the national economy for a certain period are recorded according to certain principles and formats (Bank of Korea, 2007).

The basic structure of the input-output table is shown in figure 5. The longitudinal direction (column direction) of the figure represents the input structure used for production activities in each industry, and is divided into two parts, intermediate input indicating input of raw materials and value added indicating labor or capital input. The sum of these two parts is called total input.

The horizontal direction (row direction) of the figure shows the distribution structure of products produced in each industry, and is divided into two parts: intermediate demand sold as intermediate goods and final demand sold as consumer goods, capital goods and export goods. The sum of this intermediate demand and the final demand is called the total demand and the sum here is the total output. The total output is always equal to the total input.

<table>
<tr><td colspan="2" rowspan="2">output
Input</td><td colspan="2">endogenous</td><td colspan="3">exogenous</td><td rowspan="2">Total output</td></tr>
<tr><td>industry j</td><td>Intermediate demand</td><td>Final demand</td><td>Total demand</td><td>Import</td></tr>
<tr><td rowspan="2">endogenous</td><td>industry i</td><td>x_{ij}</td><td>$\sum_{j=1}^{n} x_{ij}$</td><td>F_i</td><td>Y_i</td><td>M_i</td><td>X_i</td></tr>
<tr><td>Intermediate input</td><td>$\sum_{i=1}^{n} x_{ij}$</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>exogenous</td><td>Value added</td><td>V_j</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Total input</td><td>X_j</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Figure 5. Basic structure of Input-output table

The input-output table can be divided into the endogenous sector and the exogenous sector. The endogenous sector is the central part of the Input-Output table, in which interim demand and intermediate inputs are recorded, and the values are determined in the model. The exogenous sector is the thermal sector, which includes the final demand and export sectors such as consumption, investment, and exports, and the primary inputs and value-added sectors such as wages and other, and values are determined outside the model. This part is the most difficult part of the input-output table creation process and is the most important part in analyzing and using the generated table.

In the input-output table, the final demand sector is set up with six items and deductions: private consumption expenditure, government consumption expenditure, private fixed capital formation, government fixed capital formation, inventory increase and exports. The outline of these is as follows.

Private consumption expenditure is the sum of the final spending on household goods and services and private nonprofit organizations (private educational institutions, religious organizations, trade unions, private non-profit medical institutions, sports organizations, etc.) Non-market products that produce at a price that is free or economically meaningless for the household or society as a whole. Therefore, the activities of nonprofit organizations that provide services to enterprises are excluded.

Government consumption expenditure refers to current expenditure on goods and services for general government activities aimed at unilaterally providing services for the public interest in the activities of the government, where general government activities include general administration, defense, Education and research, and other public services. Therefore, government consumption expenditure is the share of general government subsidy services such as education and research, medical and health, social welfare, hygiene and cultural services, And the amount of self-consumption of the general government excluding the service sales to the government.

Fixed assets (excluding land) purchased by corporations, private nonprofit organizations and general government, including buildings, machinery, etc., and intangible fixed assets such as computer software, construction costs by self-account, and private housing construction costs are included in fixed capital formation. The expenditure of households, corporations and private nonprofit organizations is divided into private fixed capital formation and general government and government corporation expenditure is fixed capital formation.

The actual amount of variation (differences between term and base adjustments) between raw materials, fuels, semifinished products, supplies, and finished products that are held for production and sale by each industry sector is called inventory increase. Therefore, increase increase refers to the change in stocks held by producers or on the distribution channels, except for changes in inventories of inventories owned by households, private nonprofit organizations and the general government.

Exports are defined as the export transactions of reunions and non-contract services for foreigners made by residents engaged in long-term production activities in the country and are subject to prior transactions such as international transfers of interest or dividend profits, remittances by overseas Koreans, Short-term capital and financial transactions by foreign exchange, stocks, bonds, etc. are excluded. The export is evaluated on FOB (free on board) price.

Income is defined as income from reunions and non-factor services from foreign countries, excluding factor income transactions and financial transactions. The evaluation of imports is based on CIF (price + premium + freight) price, which means that imports are evaluated on the same basis as domestic products. Actually, it is virtually impossible to separate freight and insurance premiums from CIF prices.

In the value-added sector, value-added refers to the difference between output and production of intermediate goods, and consists of four items: employee compensation, operating surplus, fixed capital consumption, and net production tax.

The outline of these is as follows.

Employee remuneration shall be paid in cash or in kind, in the form of any periodic or irregular basis, received as a remuneration of labor provided for the production of a worker residing in the country, whether domestic or foreigner, full-time or temporary employment. Income tax and medical insurance premiums are before deductions.

The operating surplus consists of employee surplus, fixed capital expenditure and net production tax deducted from the total value added, which consists of corporate surplus in each industry sector, net interest paid, and net payment for land.

Fixed capital expenditure is a portion of the total output to replace fixed assets such as machinery that have been consumed in the production process. In addition to the abrasion caused by the use in the production process, it also includes the consumption of aging due to the elapse of time, technological development, obsolescence, etc., and in the category of capital goods where fixed capital expenditure is included, Other buildings and facilities built for defense purposes are excluded because they do not depreciate.

The net production tax is the deduction of the subsidy from the production tax. The production tax is levied on production taxes such as VAT, special consumption tax, etc., which are imposed when the producer uses the goods and services for production, sale or other purposes, and other production vertical arrangements imposed on the ownership or lease of the land, The subsidy, which is deductible, refers to various expenditures that the government grants to producers free of charge for the purpose of promoting exports, subsidizing prices, preserving deficits, and promoting production.

2) Multiplier analysis in Leontief input-output model

The production function of the model assumes a Leontief production function. The Leontief production function adopts the assumptions of constant return to scale, diminishing returns, and fixed coefficients. Such assumptions signify that a minimum input is required for each good to produce each good. Therefore, if the product quantity of industry *i* necessary to produce one unit of good in industry j is defined as a_i, the Leontief production function can be expressed as follows.

The total quantity of goods produced in industry *j*, denoted by X_j, can be expressed as follows.

$$X_j = \min(\frac{x_{1j}}{a_{1j}}, \frac{x_{2j}}{a_{2j}}, \dots, \frac{x_{nj}}{a_{nj}}) \quad (1)$$

Here, a_{ij} represents the quantity produced by industry *i* needed to produce one unit of good in industry *j*, and X_j is determined by the smallest value among the values in $\frac{x_{1j}}{a_{1j}}, \frac{x_{2j}}{a_{2j}}, \dots, \frac{x_{nj}}{a_{nj}}$. Therefore, equation (1) can be expressed as follows.

$$x_{1j} \geq a_{1j}X_j, x_{2j} \geq a_{2j}, X_j, \dots, x_{nj} \geq a_{nj}X_j \quad (2)$$

Since the tables comprise the data of the production of a real country, however, each good is an economic good, not a free good. That is, since there is no idle resource, the following equality relation is established.

$$a_{ij} = \frac{x_{ij}}{X_j} \tag{3}$$

aij in the equation above is an input coefficient, and it represents the ratio of the goods of industry *i* required to produce goods in industry *j*. By the same principle, if the total amount of value added necessary to produce one unit of good in industry *j* is defined as V_j, the value-added coefficient *Vj* is defined as equation (4), and it indicates the ratio of value added necessary to produce goods in industry *j*.

$$v_j = \frac{V_j}{X_j} \tag{4}$$

Here, the input coefficient arranged in the same shape as the endogenous sector of the tables is called the input coefficient matrix A, and the value-added coefficient arranged in the same shape as the endogenous sector of the inter-industry relation table is called the value-added coefficient matrix A^v. In addition, the input coefficient arranged in a vector form is called the input coefficient vector. In the input coefficient vector, the sum of all the input coefficients and value-added coefficients of a specific industry in the row direction is one.

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \tag{5}$$

$$A^v = [v_1, v_2, \cdots\cdots, v_n] \tag{6}$$

Meanwhile, examining the demand–supply relation of the products of each industrial sector in the tables, the demand–supply equation is shown in equation (7) below can be formulated as the total product matches the amount obtained when the revenue is deducted from the sum of intermediate demand and final demand.

$$\begin{cases} a_{11}X_1 + a_{12}X_2 + a_{13}X_3 + \cdots + a_{1n}X_n + Y_1 - M_1 = X_1 \\ \vdots \\ a_{i1}X_1 + a_{i2}X_2 + a_{i3}X_3 + \cdots + a_{in}X_n + Y_i - M_i = X_i \\ \vdots \\ a_{n1}X_1 + a_{n2}X_2 + a_{n3}X_3 + \cdots + a_{nn}X_n + Y_n - M_n = X_n \end{cases} \tag{7}$$

Here, Y_i represents the final demand in segment i and M_i represents the revenue in segment i. The equation can be represented as the following matrix.

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} & \cdots & a_{1j} & \cdots & a_{1n} \\ & & & \vdots & & & \\ a_{i1} & a_{i2} & a_{i3} & \cdots & a_{ij} & \cdots & a_{in} \\ & & & \vdots & & & \\ a_{n1} & a_{n2} & a_{n3} & \cdots & a_{ij} & \cdots & a_{in} \end{bmatrix} \begin{bmatrix} X_1 \\ \vdots \\ X_i \\ \vdots \\ X_n \end{bmatrix} + \begin{bmatrix} Y_1 \\ \vdots \\ Y_i \\ \vdots \\ Y_n \end{bmatrix} - \begin{bmatrix} M_1 \\ \vdots \\ M_i \\ \vdots \\ M_n \end{bmatrix} = \begin{bmatrix} X_1 \\ \vdots \\ X_i \\ \vdots \\ X_n \end{bmatrix} \tag{8}$$

$$\mathbf{AX} + \mathbf{Y} - \mathbf{M} = \mathbf{X} \tag{9}$$

Here, X represents the total product vector, Y represents the final demand vector, and M represents the revenue vector. The equation can be expanded and solved for X as follows.

$$
\begin{aligned}
&\mathrm{X} - \mathrm{AX} = \mathrm{Y} - \mathrm{M} \\
&\leftrightarrow (\mathrm{I} - \mathrm{A})\mathrm{X} = \mathrm{Y} - \mathrm{M} \\
&\leftrightarrow \mathrm{X} = (\mathrm{I} - \mathrm{A})^{-1}(Y - M) \\
&\leftrightarrow \mathrm{X} = (\mathrm{I} - \mathrm{A})^{-1}Y_d
\end{aligned} \tag{10}
$$

Here, I represents unit vector and Y_d is the final demand *(Y-M)* for domestic products. $(I - A)^{-1}$ is the Leontief inverse matrix. If the Leontief inverse matrix and the final demand value are known, the total product amount, which is directly and indirectly induced in each industrial sector, can be found out by using the equation above. That is, the Leontief inverse matrix can be developed into an equation as shown in Equation (11), and the unit matrix I in the expansion becomes the direct output effect of each industrial sector to satisfy the final demand for the product of each industrial sector when the final demand occurs by one unit at a time and A becomes the input of intermediate goods (primary production ripple effect) needed to produce one unit of product in each industrial sector. In addition, A^2 becomes the input amount of intermediate goods (secondary production ripple effect) necessary for the production of each industrial sector product appeared as a result of the primary output effect, and A^3 and A^4 can be interpreted by the same method. Eventually, the Leontief inverse matrix signifies the total amount of production directly and indirectly induced in the entire economy to satisfy one unit of the final demand.

$$\mathbf{(I - A)^{-1}} = \frac{\mathbf{1}}{\mathbf{1 - A}} = \mathbf{1 + A + A^2 + A^3 + A^4} \cdots \tag{11}$$

Also, the direct and indirect value added induced into the entire economy in the production process of each industrial sector can be calculated using the input coefficient and value-added coefficient.

$$\text{value added multiplier} = \widehat{A^v}(I - A)^{-1}Y_d \tag{12}$$

Here, $\hat{A^v}$ signifies the diagonal matrix of the value-added input coefficient matrix. In addition, the number of workers induced in the entire economy in the production process of each industrial sector can be calculated in a similar way. If employment vector l is defined as the labor necessary to produce one unit of good in industry j shown in matrix and its diagonal matrix as $\hat{l}$, the number of direct and indirect laborers induced in the entire economy in the production process of each industrial sector is as the following equation.

$$\hat{l}(I - A)^{-1}Y_d \tag{13}$$

3.3.2. Indicators to measure intersectoral linkages

The role of an industry in the national economy can be found through the interdependence among industries by using the tables, and the interdependence relationship appears as backward and forward linkage effects. The backward linkage effect signifies the effect of increasing the demand for the goods in other sectors by the production of goods to satisfy the demand, and the forward linkage effect signifies the effect of inducing goods production in other sectors that use the goods production in the corresponding sector as the intermediate input. The backward linkage and forward linkage can be obtained using the Leontief inverse matrix.

The analytical approach for the backward linkage and forward linkage is based on the Leontief's input-output framework (Miller, Blair 1985, 2009). In matrix notation basic equations for Input-Output analysis is:

$$X = AX + Y \tag{14}$$

where, Y is final demand vector. Equation (13) is the fundamental equation of the Leontief model, which denotes that the gross output (X) is the sum of intermediate input demand (AX) and final demand (Y). Solving equation (13) for total output equation (14) where I is an $N \times N$ identity matrix and B is the Leontief inverse matrix.

$$\mathrm{X} = (\mathrm{I} - \mathrm{A})^{-1} Y = BY \tag{15}$$

To measure the inter-industry linkage we must compute its forward linkage (FL) and backward linkage (BL). Based on the Leontief framework, Rasmussen (1956) and Hirschman (1958) suggested (15) and (16) below as indicators of strength of BL and FL.

$$\mathrm{BL} = \frac{1}{n} \sum_{i=1}^{n} b_{ij} = \frac{1}{n} B_{\cdot j} \tag{16}$$

and

$$\mathrm{FL} = \frac{1}{n} \sum_{j=1}^{n} b_{ij} = \frac{1}{n} B_{i\cdot} \tag{17}$$

where, B is the Leontief inverse matrix and parameters B_j and B_i indicate the value of inputs from industry i used by industry j to produce one unit of output in the economy. In addition, b_{ij} are the coefficients of matrix B, where Hazari (1970) suggested modification to the measures by dividing the terms in (15) and (16) by a global average as in (17) below (Amin and Jaafar, 2014):

$$\frac{1}{n^2}\sum_{j=1}^{n}\sum_{i=1}^{n} b_{ij} = \frac{1}{n^2}\sum_{i=1}^{n} B_{\cdot j} = = \frac{1}{n^2}\sum_{j=1}^{n} B_{i\cdot} \tag{18}$$

where n is the numbers of industry in the economy. This allow inter-industry comparison. With normalizations procedure, the BL and FL linkage indicators become:

$$\mathrm{BL} = U_j = \frac{\frac{1}{n}B_{\cdot j}}{\frac{1}{n^2}\sum_{i=1}^{n} B_{\cdot j}} \tag{19}$$

And

$$\mathrm{FL} = U_j = \frac{\frac{1}{n}B_{i\cdot}}{\frac{1}{n^2}\sum_{i=1}^{n} B_{i\cdot}} \tag{20}$$

These index that represents the backward linkage effect is called the index of the power of dispersion (IPD) and the index that represents the forward linkage effect is called the index of the sensitivity of dispersion (ISD). Defining r_{ij} as the element in row i, column j of the production-inducement coefficient matrix, the IPD and ISD can be obtained as the following equations.

The IPD and ISD can be used to estimate the economic role that the applicable industry is performing within the national economy. Since the value of both coefficients is one when the IPD and ISD of the industry to analyze is the same as the average of the entire industries, the relatively high and low of the corresponding coefficient can be determined by comparing it to one. The industry can be classified into the intermediate demand manufacturing industry if both IPD and ISD are higher than one, final demand manufacturing industries if the IPD is higher than one and the ISD is lower than one, intermediate demand primary industry if the IPD is lower than one and the ISD is higher than one, and final demand primary industry if both IPD and ISD are lower than one.

All indices mentioned above are measure of sectoral interdependence which do not account for the level of economic activities and the policy context of key sectors computation (Lenzen, 2003; Soofi, 1992; Cuello and Mansouri 1992, Amin and Jaafar, 2014). To remedy this limitation, researchers recommended incorporating weighting scheme into BL and FL linkage measures. If we refer to Soofi (1992), Claus and Li (2003), the weighted BL and FL linkage can be measured as follows.

$$b_{ij}^{w} = b_{ij}\frac{y_i}{\sum_{i=1}^{n} y_i} \qquad (21)$$

and

$$B_{\cdot j}^{w} = \frac{1}{n}\sum_{j=1}^{n} b_{ij}^{w} \quad (22)$$

Similar to (18) and (19), the weighted BL and FL are:

$$\mathrm{BL} = \mathrm{U}_{j}^{w} = \frac{\frac{1}{n}B_{\cdot j}^{w}}{\frac{1}{n^2}\sum_{i=1}^{n} B_{\cdot j}^{w}} \quad (23)$$

And

$$\mathrm{FL} = \mathrm{U}_{ji}^{w} = \frac{\frac{1}{n}B_{i\cdot}^{w}}{\frac{1}{n^2}\sum_{i=1}^{n} B_{i\cdot}^{w}} \quad (24)$$

where, *w* indicates the weights of *BL* and *FL*, and b_{ij} are the coefficients of Leontief inverse matrix. Under this method, a sector is considered to have strong backward linkage if $U_j > 1$ and a strong forward linkage if $U_i > 1$ (Amin and Jaafar, 2014).

Another measure of industrial potential that account for relative size of a sector is based on output-to-final demand elasticity (Mattas and Chandra 1994; Ciobanu *et al.* 2004; Miller, Blaire 2009). This measure of industrial potential quantifies the impact of one percent change in final demand to the percentage change in total output (Amin and Jaafar, 2014). Following Mattas & Chandra (1994), the output-to-final demand elasticity (output elasticity) of sector j, which can be denoted by OE_{xyj}, is calculated as follows:

$$\mathrm{BL} = OE_{xyj} = \sum_{i=1}^{n} b_{ij} \frac{y_j}{x} = B_{.j} \frac{y_j}{x} \tag{25}$$

Essentially, OE_{xyj} (BL in the output-to-final demand elasticity of sector j) is similar to equation (20) or (22) but it is weighted by the ratio of final demand to total gross output. As such, OE_{xyj} is a measure of BL and taken together with a similarly weighted forward measure, could be used for key sectors' identification. The forward linkage output-to-final demand elasticity which can similar be indicated by OE_{xyi} can is calculated as follows (Amin and Jaafar, 2014):

$$\mathrm{FL} = OE_{xyi} = \sum_{j=1}^{n} b_{ij} \frac{y_j}{x} = B_{i.} \frac{y_j}{x} \tag{26}$$

where OE_{xyi} (FL in the output-to-final demand elasticity of sector i). Under this method, higher BL is associated with larger value of OE_{xyj}. Similarly, higher FL is associated with larger value of OE_{xyi}.

In economics, elasticity is the measurement of how responsive an economic variable is to a change in another. Usually, an elastic variable (with elasticity value greater than 1) is one which responds more than proportionally to changes in other variables. In contrast, an inelastic variable (with elasticity value less than 1) is one which changes less than proportionally in response to changes in other variables.

However, the concept of output elasticity does not exactly match the general concept of elasticity, since it refers to a change in the total output due to changes in the final demand of industry i. Here, output elasticity is the size / total output of the total output increased due to the final demand of the year. The denominator is the same for all industrial sectors, and is weighted by the size of final demand by industry in the molecule.

3.3.3. New Industry Impacts in the Input–Output Model

One of the limitations of the industry association analysis is that it is difficult to directly analyze if the industry to be analyzed is not defined in the industry association table. In order to overcome these limitations, we can use slightly different methods depending on the characteristics of the industry, the range of available data, and the effect to be analyzed.

The common method is based on the Wolsky (1984). Thereafter, literature such as Gillen and Guccione (1990), Ferrer and Ayres (2000) and Miller and Blair (2009) are mainly cited. The method that can be analyzed when there is no industry in the industry association table can be used as follows depending on whether or not the industry structure is reflected in the industry association representation.

The first is the final demand approach. If a new industry emerges in an economy of two industries, Miller and Blair (2009) explain that economic impacts of this third industry can be obtained as follows: Suppose that you can estimate the input from Sector 1 and Sector 2 for the new Sector 3. That is, the coefficients a_{13} and a_{23} are known. We also know the total production of the three sectors, X_3. In this case, new demand for sector 1 and sector 2 due to production by new sector 3 is $a_{13}X_3$ and $a_{23}X_3$, respectively. In other words, we can see this new demand as exogenous fluctuation of the original two sectors.

Therefore, if a_{ij} is used to denote the elements of the Leontief's inverse, we can get the following results.

$$\mathrm{X} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} a_{13}X_3 \\ a_{23}X_3 \end{bmatrix} = \begin{bmatrix} a_{11}a_{13}X_3 + a_{12}a_{23}X_3 \\ a_{21}a_{13}X_3 + a_{22}a_{23}X_3 \end{bmatrix} \tag{27}$$

Estimates of the economic impacts of new industries derived so far are somewhat conservative. In other words, the total subordination of the new sector of the economy reflects the fact that the new industry not only can purchase input from existing sectors, but also can supply its own products to other sectors of the economy. In other words, ultimately, the overall technical structure of the economy can change. First, there will be rows and columns of direct input coefficients associated with inputs and purchases for the new sector, and the elements of the original matrix A will change.

a_{13}, a_{23}, a_{31}, a_{32}, and a_{33} will be needed to create a complete close model including the new industry. Where a_{13} and a_{23} are estimates of how much the existing industry will buy from the new sector. If we know the total output X_3 of sector 3 at this time, the basic equilibrium equation is as follows.

$$
\begin{aligned}
(1-a_{11})X_1 - a_{12}X_2 - a_{13}X_3 &= Y_1 \\
-a_{21}X_1 + (1-a_{22})X_2 - a_{23}X_3 &= Y_2 \\
-a_{31}X_1 - a_{32}X_2 + (1-a_{33})X_3 &= Y_3
\end{aligned}
\tag{28}
$$

To put exogenous variables on the right side, we rearrange them and express them in matrix form as follows.

$$
\begin{bmatrix} (1-a_{11}) & -a_{12} & 0 \\ -a_{21} & (1-a_{22}) & 0 \\ -a_{31} & -a_{32} & 1 \end{bmatrix}
\begin{bmatrix} X_1 \\ X_2 \\ X_3 \end{bmatrix}
=
\begin{bmatrix} Y_1 + a_{13}X_1 \\ Y_2 + a_{23}X_1 \\ -(1-a_{33})X_3 \end{bmatrix}
\tag{29}
$$

Gillen and Guccione (1990), Ferrer and Ayres (2000), and others, especially how to estimate a_{13}, a_{23}, a_{31}, a_{32} is a problem to be solved by this method.

3.4 Empirical Analysis

3.4.1. Data

The input-output table is the main data for the input-output analysis. In this study, we used the Input-Output table of 2005 ~ 2014 period issued by Bank of Korea. In the Bank of Korea, a benchmark table is issued every five years. In the rest of the period, the available data is limited, and a table using the semi-survey method is used to estimate the remaining data using the modified RAS method is. The input-output table for 2005 and 2010 used in this study is the benchmark table issued through the whole survey and the table for 2006, 2007, 2008, 2009, 2011, 2012, It is a prepared table. In addition, the Input-Output table used in this study is a Type 1 input-output table that does not include the flows of money in and out of households and the effect.

In addition, input-output analysis for the renewable energy industry requires a process to define the input structure of the renewable energy industry first. The reason why this process is necessary is to estimate the industrial ripple effects of each renewable energy source in this study, but this is not defined as an independent industry sector in the Input-Output table.

When an industry is a new industry that is not defined in the Input-Output table, the most commonly used method is the final-demand approach. The final demand approach is a method of analyzing the impact of industry A on the basis of the increase in final demand of each sector and the investment cost, assuming that production in the new industry A can be estimated by input from the existing industries B and C. However, the reliability of this data is very important because the researcher must first define the scope and classification of the industry and estimate the investment cost of each factor industry to analyze it using the final demand approach. In this study, "Korea Energy Economics Institution", which is the representative organization responsible for research on energy policy in Korea, and "Korea Energy Agency", which is responsible for energy policy and research management, "Study on Efficiency and Policy Measure for Renewable Energy Sources", And used the elementary industry classification and investment structure of the renewable energy source. This investment structure was also used in Korea for establishing the "4th New & Renewable Energy Basic Plan" and the "3rd New & Renewable Energy Basic Plan". It can be said that the investment structure is relatively credible.

It is also necessary to define the resource development industry as compared with the renewable energy industry. There are many industrial groups participating in resource development, but there are no established or internationally accepted criteria for classifying this industry group. In addition, the Input-Output table covers the economic activities that occur in Korea. Korea's resource development is mainly led by the overseas resource development industry, and the mining industry is also suffering from limitations of resources and deterioration of mining conditions. However, referring to Jung (2013), 'crude oil and natural gas' sector and 'Mining and Quarrying' sector are defined as the industry related to resource development in the Input-Output table and it is compared with the renewable energy industry.

3.4.2. Analysis flow

The process of this study is as follows. First, reclassify the industry classification of the Input-Output table. In this study, Input-Output table is used for each year from 2005 to 2014. Whenever Benchmark is issued, the Bank of Korea is in the process of adjusting the industrial classification of the Input-output table to match the industry trend at that time. Therefore, the industry classification of 2005, 2006, 2007, 2008 and 2009 and the input-output table of 2010, 2011, 2012, 2013 and 2014 do not match. Therefore, it is necessary to rearrange the Input-Output table, employment input table, value added input table.

Secondly, defines the structure of the investment cost of each source of the renewable energy industry. In order to estimate the economic impacts of renewable energy sources, the element industry is sorted according to the industrial classification in the Input-Output table reclassified in the previous stage for each renewable energy source, and the structure of investment cost by source is summarized.

Third, the Leontief inverse matrix was calculated and the industrial characteristics of the renewable energy sources and its changes were observed by using the calculated Leontief inverse matrix to obtain the production inducement effect, value added inducement effect, employment inducement effect, forward linkage and backward linkage. The Leontief inverse matrix is the most basic form of data to obtain production inducement, value added inducement, employment inducement, forward linkage, and backward linkage. We compared these results with those of 'crude oil and natural gas' and 'mining and quarrying'.

Fourth, to obtain the output-to-final demand elasticity proposed by Mattas and Chandra (1994), we calculated the weighted mean Leontief inverse matrix with output-to-final demand ratio. Based on these results, the output-to-final demand elasticity was calculated and compared with the forward linkage and backward linkage obtained by using the conventional Leontief inverse matrix.

3.4.3 Results

3.4.3.1. Multiplier analysis

In this chapter, we will examine the results of the multiplier analysis of the renewable energy industry and the resource development industry according to the methodology described in Section 3.3. First, we compare the analysis results of the renewable energy industry with the average of the resource development industry and the whole industry.

First, the output multiplier is analyzed by table 16. As described in Section 3.3, an output multiplier is a unit of output that occurs directly or indirectly, caused by a single unit of final demand for the industry. Looking at the average of Korean industry, the average production inducement effect from 2005 to 2014 increased by about 0.053 from 1.855 to 1.908. Since 2010, production inducement effects have tended to decline somewhat in 2011 and 2012, due to a decline in intermediate inputs throughout the economy.

As a result, the output multiplier of the renewable energy industry has generally increased. In terms of energy sources, the production inducement coefficient of the biofuel sector decreased by 0.033 from 1.947 in 2005 to 1.914, and the production induction coefficient of all other energy sources increased.

In 2014, the renewable energy source with the largest output multiplier was Biogas> Wind> Geothermal> Micro hydro> Waste> Fuel cell> Solar thermal> Photovoltaic> Biofuel> Biomass. On the other hand, if the output multipliers are listed in order of increasing number, they are Geothermal> Biogas> Micro hydro> Biomass> Solar thermal> Waste> Wind> Fuel cell> Photovoltaic> Biofuel. Comparing the output multipliers of Biogas and Wind, the output multiplier of Wind was higher in 2005, but the output multiplier of Biogas is increased more and it is analyzed that it has higher output multiplier than wind in 2014.

Compared with the resource development industry, the output multiplier of the renewable energy industry is higher in all energy sources. This is because the crude oil and natural gas industries are in the early stage of development of the resource development industry in Korea, and they are dependent on foreign companies for resource development project evaluation and mining development work. In addition, the renewable energy industry has a high production inducement effect compared with the average of all industries.

Table 16. Output multiplier of renewable energy industry and Resource development industry

	PV	Wind	Fuel cell	Micro hydro	Waste	Biogas	Biomass
2005	1.993	2.264	2.083	2.164	2.113	2.234	1.876
2006	2.032	2.290	2.097	2.205	2.133	2.257	1.878
2007	2.028	2.307	2.108	2.222	2.150	2.283	1.897
2008	2.050	2.317	2.099	2.220	2.154	2.298	1.903
2009	2.088	2.348	2.113	2.233	2.160	2.320	1.912
2010	2.083	2.297	2.132	2.200	2.182	2.300	1.940
2011	2.047	2.291	2.103	2.183	2.174	2.301	1.933
2012	2.025	2.285	2.090	2.160	2.164	2.302	1.919
2013	2.004	2.270	2.072	2.177	2.136	2.269	1.890
2014	2.002	2.292	2.103	2.202	2.150	2.296	1.913

	Geothermal	Biofuel	Solar thermal	Average of all industry	Oil & Gas	Mining & Quarrying	
2005	2.160	1.947	2.051	1.855	1.330	1.722	
2006	2.184	1.970	2.092	1.876	1.335	1.707	
2007	2.214	1.934	2.081	1.868	1.357	1.705	
2008	2.232	1.937	2.062	1.863	1.380	1.719	
2009	2.243	1.932	2.077	1.863	1.541	1.731	
2010	2.265	1.880	2.071	1.898	1.631	1.714	
2011	2.262	1.868	2.061	1.894	1.640	1.711	
2012	2.252	1.876	2.048	1.890	1.612	1.669	
2013	2.231	1.891	2.058	1.904	1.750	1.719	
2014	2.239	1.914	2.088	1.908	1.583	1.723	

The results of the value added multiplier are shown in table 17. Respectively. A value added multiplier is a value-added unit resulting from direct or indirect production caused by a final demand unit. If we look at the Korean industry in the first place, the average value added inducement effect decreased and increased repeatedly during 2005 ~ 2014, and recovered to 0.692 from 0.694 in 2005 to 0.692 in 2014. Employees' remuneration and operating surplus are the biggest influences in the increase / decrease of the value added ratio. From 2005 to 2009, the remuneration of employees in the whole economy declined mainly. From 2010 to 2014, however, operating surplus decreased slightly.[3]

Comparing the value added multipliers of the renewable energy industry with the average of all industry averages, the value added inducement effect of the average of all industry average is almost unchanged. Can be. This result implies that each factor industry of renewable energy has had a large effect on income increase in Korea during this period. However, when comparing the magnitude of value added effect, the value added multiplier is higher than the average of all industry average in all periods, and only the biofuel is the energy source. From 2009 and 2011, Geothermal also has a value added multiplier higher than the average of all industry average.

As of 2014, the value added effect of each renewable energy source was compared with Biofuel> Geothermal> Biogas> Wind> Micro hydro> Waste> Biomass> Fuel cell> Photovoltaic> Solar thermal. On the other hand, in order of

[3] Bank of Korea (2014a, 2014b, 2015, 2016)

increasing value added multiplier, Geothermal> Biogas> Waste> Biomass> Micro hydro> Fuel cell> Biofuel> Wind> Photovoltaic> Solar thermal.

Comparing the value added multipliers of the resource development industry and the renewable energy industry, the value added multiplier of the renewable energy industry is relatively lower than that of the resource development industry. The value added multiplier of the resource development industry is high not only in Korea but also in other developed countries, which is due to high surplus of operating surplus and fixed capital compared to other industries.

Table 17. Value-added multiplier of renewable energy industry and Resource development industry

	PV	Wind	Fuel cell	Micro hydro	Waste	Biogas	Biomass
2005	0.607	0.673	0.596	0.658	0.599	0.653	0.598
2006	0.600	0.665	0.583	0.656	0.590	0.649	0.593
2007	0.584	0.648	0.570	0.644	0.579	0.636	0.585
2008	0.527	0.584	0.524	0.597	0.525	0.576	0.518
2009	0.547	0.616	0.547	0.615	0.553	0.607	0.552
2010	0.603	0.648	0.597	0.657	0.613	0.652	0.617
2011	0.566	0.616	0.561	0.623	0.584	0.621	0.588
2012	0.568	0.620	0.560	0.624	0.582	0.626	0.586
2013	0.585	0.658	0.588	0.657	0.606	0.660	0.606
2014	0.609	0.682	0.613	0.680	0.629	0.685	0.623
	Geothermal	Biofuel	Solar thermal	Average of all industry	Oil & Gas	Mining & Quarrying	
2005	0.669	0.729	0.542	0.694	0.953	0.847	
2006	0.668	0.727	0.529	0.687	0.953	0.844	
2007	0.658	0.721	0.516	0.676	0.948	0.836	
2008	0.610	0.677	0.457	0.628	0.934	0.800	
2009	0.633	0.689	0.482	0.643	0.913	0.816	
2010	0.688	0.728	0.534	0.687	0.928	0.802	
2011	0.657	0.712	0.500	0.664	0.922	0.797	
2012	0.662	0.703	0.492	0.659	0.921	0.800	
2013	0.688	0.720	0.520	0.674	0.905	0.799	
2014	0.714	0.739	0.539	0.692	0.925	0.803	

The employment multiplier is as follows. Employment multiplier is the unit of Employment that occurs due to direct or indirect production caused by the final demand unit. Looking at the Korean industry average, the average Employment multiplier is generally on a declining trend during the period from 2005 to 2014. This shows the phenomenon in which human capital is being replaced by the development of technology. The employment multiplier of Korea's total industry average decreased from 8.68 persons/billion won in 2005 to 8.04 persons/billion won in 2014 (based on 2014 prices).

Comparing the employment multiplier of the renewable energy industry with the average of all industry average, it can be seen that the employment inducement effect of the renewable energy industry is more significant than the reduction of the average of all industry average employment multipliers. This result is inferred to reflect the tendency of Korea's employment to shift from manufacturing to service industry. Therefore, this study focuses on the manufacturing of renewable energy equipments. If the power plant operation and power supply industry is considered, the employment inducement effect of the renewable energy industry is expected to increase somewhat. In 2005, the micro hydro, wind and geothermal sectors had higher employment multipliers than the average of all industries, but in 2014 the employment multipliers of all renewable energy sources were lower than the average of all industries.

As of 2014, the Employment multiplier for each renewable energy source was compared with Geothermal> Micro hydro> Biogas> Waste> Wind> Photovoltaic> Fuel cell> Biomass> Biofuel> Solar thermal. In the order of decreasing the employment multiplier, it was listed as Waste> Biofuel> Geothermal> Solar thermal> Fuel cell> Photovoltaic> Biogas> Biomass> Wind> Micro hydro.

Compared with the resource development industry, the employment inducement effect was generally higher. It seems that the resource development industry is not a labor-intensive industry but a capital-intensive industry.

Table 18. Employment multiplier of renewable energy industry and Resource development industry

	PV	Wind	Fuel cell	Micro hydro	Waste	Biogas	Biomass
2005	7.57	8.68	7.32	9.29	7.69	8.29	7.38
2006	7.54	8.52	7.02	9.23	7.51	8.11	7.28
2007	7.24	8.17	6.69	8.77	7.16	7.76	6.93
2008	6.99	7.75	6.40	8.53	6.88	7.42	6.74
2009	6.79	7.80	6.28	8.43	6.74	7.42	6.54
2010	6.88	6.17	5.66	6.97	6.87	6.24	6.03
2011	6.00	6.27	5.46	6.86	6.32	6.28	5.73
2012	6.08	6.05	5.44	6.76	6.33	6.11	5.49
2013	5.83	6.36	5.64	6.89	6.33	6.39	5.49
2014	6.10	6.65	6.06	7.18	6.68	6.77	5.84

	Geothermal	Biofuel	Solar thermal	Average of all industry	Oil & Gas	Mining & Quarrying
2005	9.23	6.59	6.18	8.68	3.60	6.86
2006	9.11	6.55	6.16	8.59	4.08	6.68
2007	8.71	6.40	5.80	8.35	5.64	6.71
2008	8.47	6.20	5.52	8.43	7.80	6.51
2009	8.21	6.26	5.57	8.35	5.04	6.40
2010	8.31	5.60	4.73	8.00	3.19	6.85
2011	7.57	5.66	4.79	8.23	3.32	6.22
2012	7.65	5.38	4.69	8.16	3.08	5.68
2013	7.58	5.44	4.85	8.10	3.80	5.82
2014	8.02	5.56	4.96	8.04	3.09	5.86

The results of the multiplier analysis are summarized for each renewable energy source and the characteristics are summarized as follows.

1) Photovoltaic

The photovoltaic industry has higher output multipliers than the average of all industries. In 2014, the output multiplier of the photovoltaic industry is 2.002, which is about 0.094 higher than the output multiplier (1.908) of the average of all industry. In the photovoltaic industry, the ecology of the industry is highly related to the semiconductor industry, and the output multiplier is generally expected to be somewhat lower. The renewable energy industry, which is defined in this study, includes civil engineering construction related to the installation of the system. The output multiplier of the photovoltaic industry is considered to be higher than the average of all industries. However, looking at the trends in 2005 and 2014, the output multipliers of the photovoltaic industry tend to decrease somewhat compared to the average output of all industry's output multipliers since 2011, and the difference between the output multipliers of the photovoltaic industry and the average of all industry is slightly reduced.

The value-added multiplier of the photovoltaic industry in 2014 was 0.609, which was 0.083 lower than the value added multiplier of 0.692 in the average of all industry, and the trend of change from 2005 was similar to the average of all industry. The change in the value added multiplier during the period from 2008 to 2011 seems to reflect the impact of the global financial crisis on manufacturing profits.

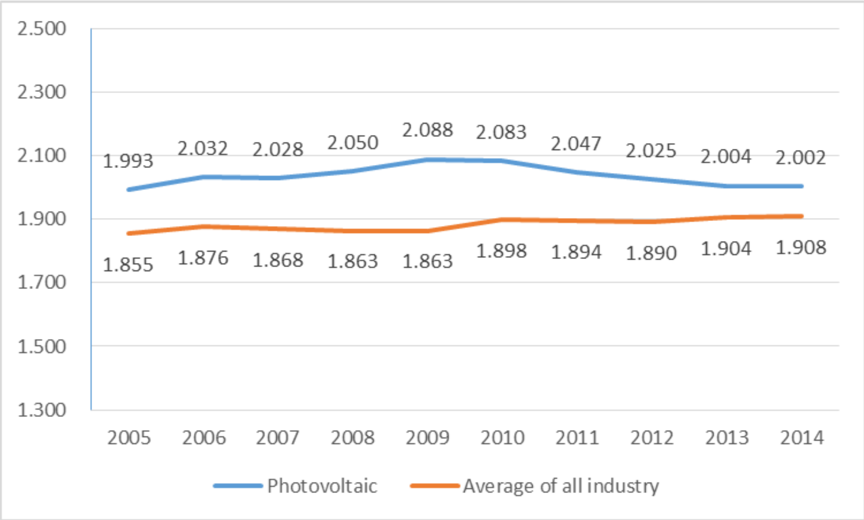

Figure 6. Output multipliers of photovoltaic industry

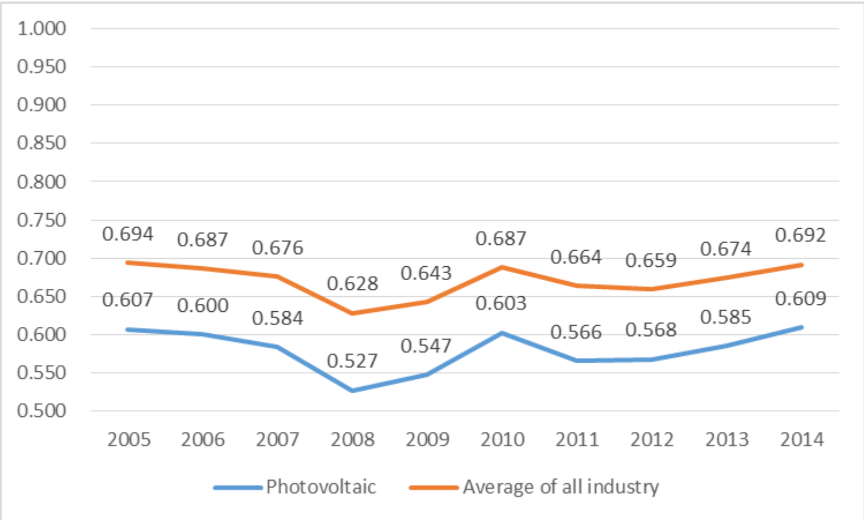

Figure 7. Value-added multiplier of photovoltaic industry

Employment multipliers in the photovoltaic industry were lower than the employment multipliers in the average of all industries. In 2005, the employment multiplier of the photovoltaic industry was 7.75 person/billion won and the employment multiplier of the average of all industry was 8.68 person/billion won, but in 2014, the employment multiplier of the photovoltaic industry was 6.10 person/billion won and the employment multiplier of the average of all industry was 8.04 person/billion won. In other words, the employment inducement effect of the photovoltaic industry is decreasing more rapidly than the employment inducement effect of the average of all industry.

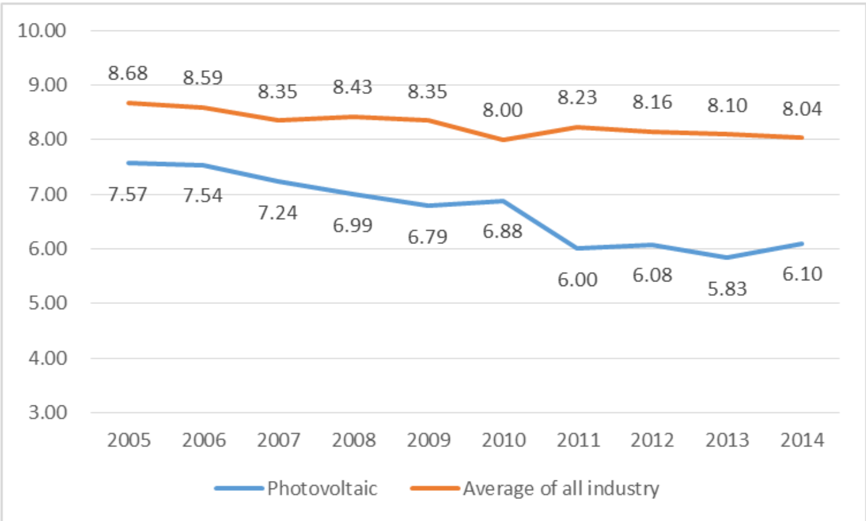

Figure 8. Employment multiplier of photovoltaic industry

2) Wind

The wind industry has higher output multipliers than average of all industries. In 2014, the output multiplier of the wind industry is 2.292, which is about 0.094 higher than the output multiplier of the average of all industry. The ecosystem of the wind power industry has a high output multiplier among the renewable energy industry because it is deeply related to the metal industry and the general machinery industry which have high production inducement effect. Looking at trends from 2005 to 2014, the output multiplier of the wind industry in 2005 was 2.264, which was 0.409 higher than the average of all industries. The output multiplier of 2014 was 2.292, which was 0.384 higher than the average of all industries.

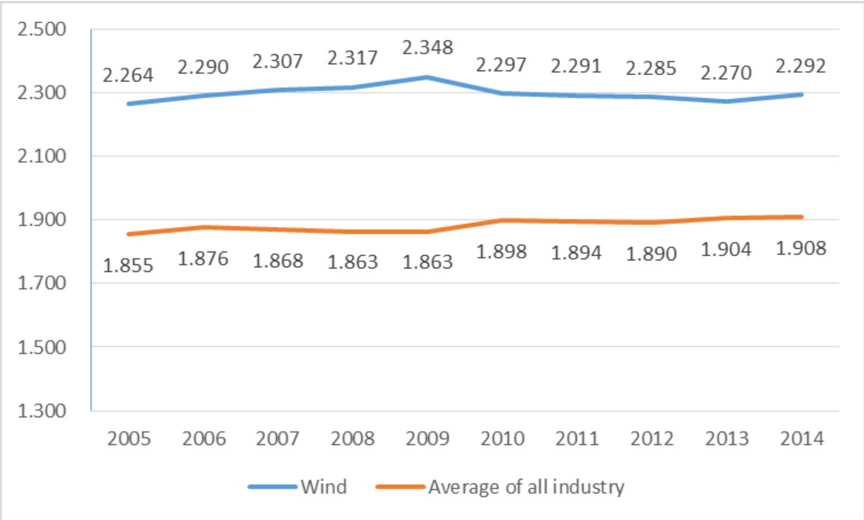

Figure 9. Output multipliers of wind industry

The value-added multiplier of the wind industry in 2014 was 0.682, which was 0.010 lower than the value added multiplier of 0.9292 in the average of all industry, which is somewhat decreasing. Looking at the employment multiplier,

In 2005, the employment multiplier of the wind industry was 8.68 person/billion won and the employment multiplier of the average of all industry was 8.68 person/billion won, however in 2014, as the difference increases, the employment multiplier of the wind industry was 6.65 person/billion won and the employment multiplier of the average of all industry was 8.04 person/billion won. Therefore, the employment environment in the wind power industry is worse than in the past.

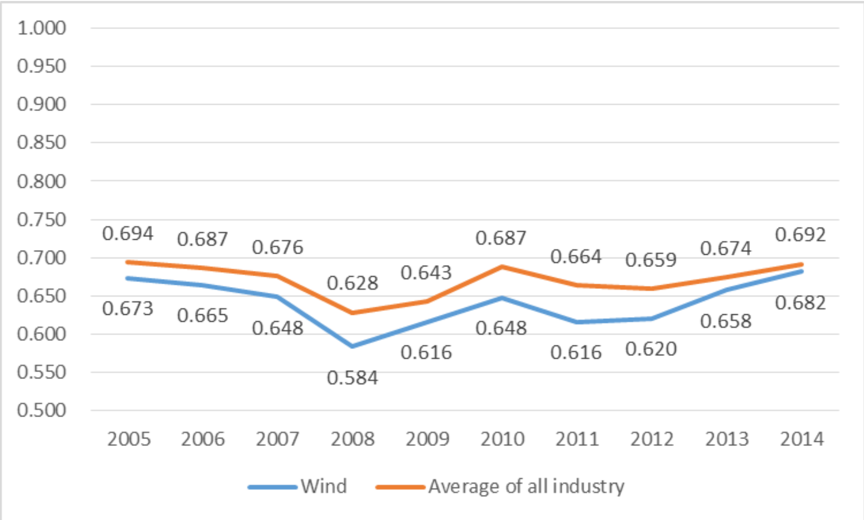

Figure 10. Value-added multiplier of wind industry

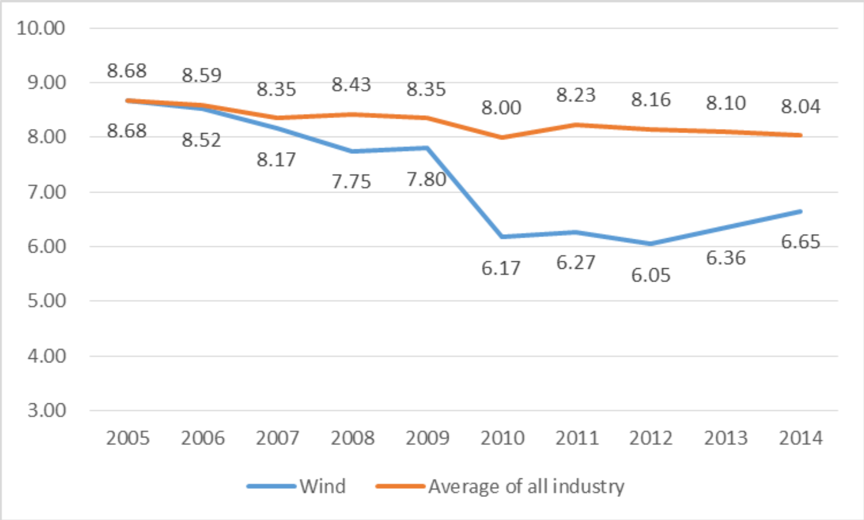

Figure 11. Employment multiplier of wind industry

3) Fuel cells

The fuel cell industry has an output multiplier that is higher than the average of all industries. The output multiplier of the fuel cell industry in 2014 is 2.103, which is about 0.095 higher than the output multiplier (1.908) of the average of all industry. The production-inducing effect of the fuel cell industry is related to the electrical equipment manufacturing industry and the chemical industry. Looking at the trends for 2005 and 2014, the output multiplier of the average of all industries has been increasing since 2011, while the output multiplier of the fuel cell industry has shown a slight decline since 2010, the output multiplier of all industries is slightly decreasing.

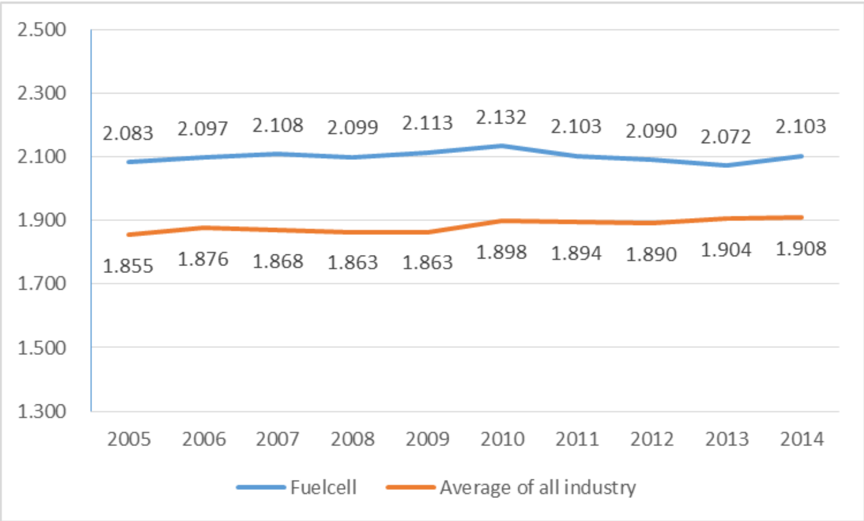

Figure 12. Output multipliers of fuel cells industry

In 2014, the value-added multiplier of the fuel cell industry was 0.613, which was

0.079 lower than the value added multiplier of 0.692 in the average of all industry, and the difference from the value added multiplier of the average of all industry was slightly smaller than that of 2005. This tendency can be interpreted as the degree to which the fuel cell industry contributes to the increase in domestic income is gradually increasing.

Employment multipliers in the fuel cell industry were lower than the employment multipliers in the average of all industries. In 2005, the employment multiplier of the fuel cell industry was 7.32 person/billion won and the employment multiplier of the average of all industry was 8.68 person/billion won, however in 2014, as the difference increases, the employment multiplier of the fuel cell industry was 6.06 person/billion won and the employment multiplier of the average of all industry was 8.04 person/billion won. The employment multipliers of the fuel cell industry have declined significantly until 2012 and then rose again, whereas the employment multipliers of the average of all industries are steadily declining,

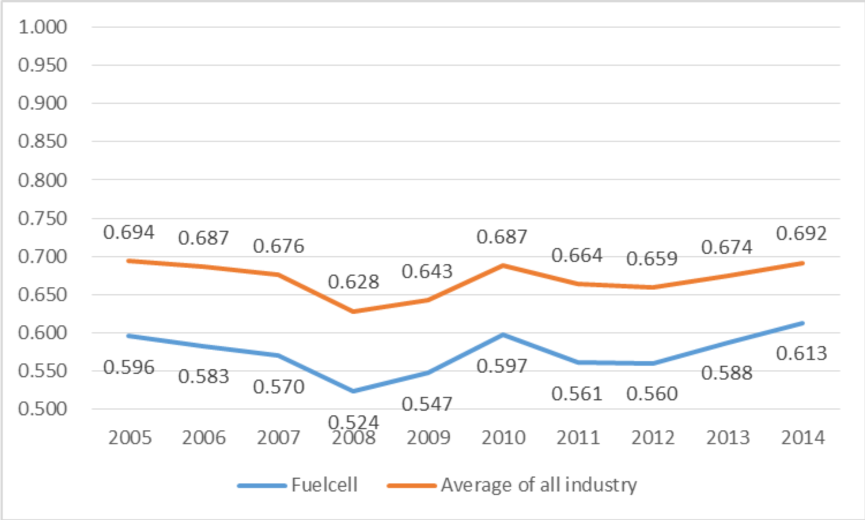

Figure 13. Value-added multiplier of fuel cells industry

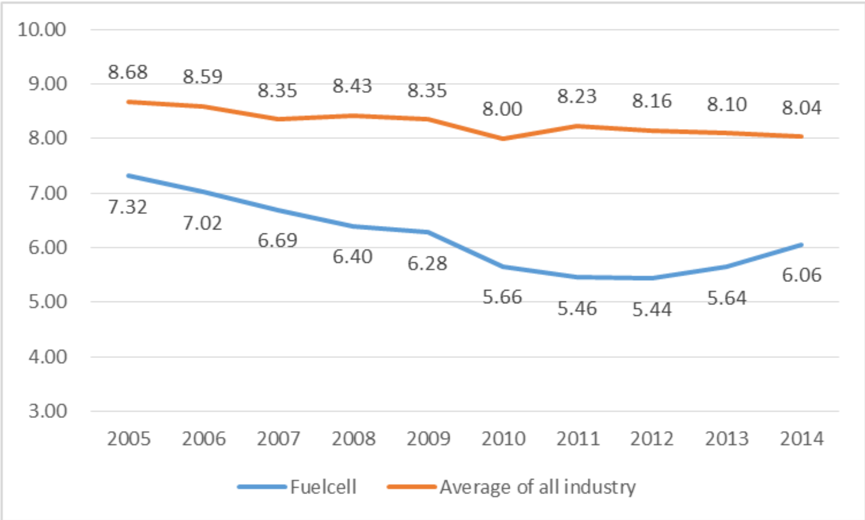

Figure 14. Employment multiplier of fuel cells industry

4) Micro Hydro

The micro hydro industry has higher output multipliers than average of all industries. In 2014, the output multiplier of the micro hydro industry is 2.202, which is about 0.294 higher than the output multiplier (1.908) of the average of all industry. The micro hydro industry is thought to have been caused by the fact that the ecology of the industry is related to various industries with high output multipliers such as metal products, general machinery, and civil engineering. Looking at the trends for 2005 and 2014, we see that the output multiplier of the micro hydro industry has increased somewhat since 2012, similar to the output multiplier of the average of all industries.

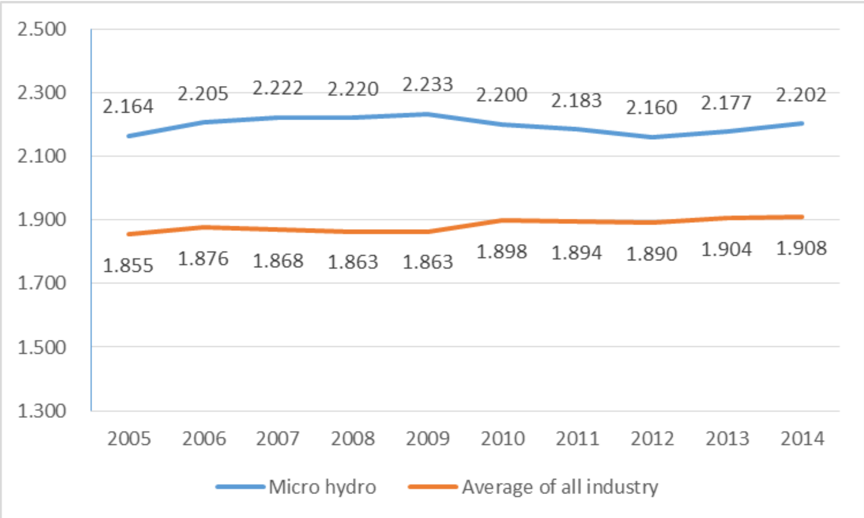

Figure 15. Output multipliers of micro hydro industry

In 2014, the value-added multiplier of the micro-hydro industry is 0.680, which is 0.012 lower than the value added multiplier of 0.692 in the average of all industry, which is slightly smaller than the value added multiplier of the average of all industry in 2005. This trend can be interpreted as the fact that the micro hydro industry contributes to the increase in domestic income is increasing little by little.

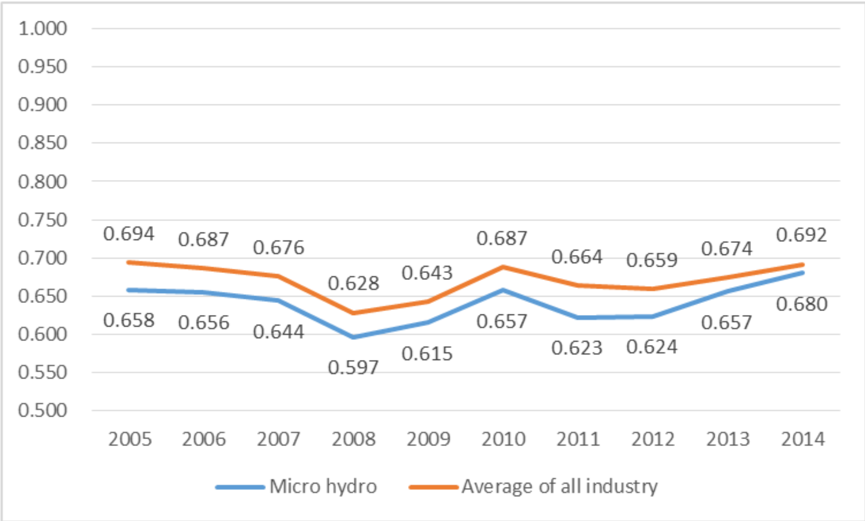

Figure 16. Value-added multiplier of micro hydro industry

Employment multipliers in the micro hydro industry were lower than the employment multipliers in the average of all industries. In 2005, the employment multiplier of the micro hydro industry was 9.29 person/billion won and the employment multiplier of the average of all industry was 8.68 person/billion won, however in 2014, as the difference increases, the employment multiplier of the micro hydro industry was 7.18 person/billion won and the employment multiplier of the average of all industry was 8.04 person/billion won.

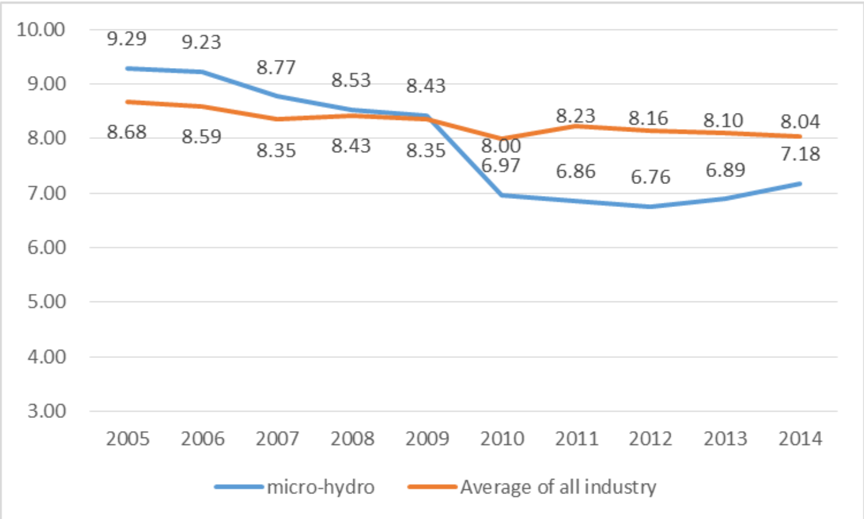

Figure 17. Employment multiplier of micro hydro industry

5) Waste energy

The waste energy industry has higher output multipliers than the average of all industries. The output multiplier of the waste energy industry in 2014 is 2.150, which is about 0.241 higher than the output multiplier (1.908) of the average of all industry. The production-inducing effects of the fuel cell industry seem to have been related to the basic chemicals and the general machinery industry. Looking at the trends for 2005 and 2014, the output multiplier of the waste industry has declined somewhat since 2010, but slightly increased in 2014, similar to the increase in the output multiplier of the average of all industries since 2011.

The value-added multiplier of the waste industry in 2014 is 0.629, which is 0.063 lower than the value added multiplier 0.692 of the average of all industry, and it shows that the difference from the value added multiplier of the average of all industry is slightly decreasing compared to 2005. This trend can be interpreted as the degree to which the waste industry contributes to the increase in domestic income is increasing little by little.

Employment multipliers in the waste industry were lower than the employment multipliers in the average of all industries. In 2005, the employment multiplier of the waste energy was 7.69 person/billion won and the employment multiplier of the average of all industry was 8.68 person/billion won, however in 2014, as the difference increases, the employment multiplier of the waste energy was 6.68 person/billion won and the employment multiplier of the average of all industry was 8.04 person/billion won.

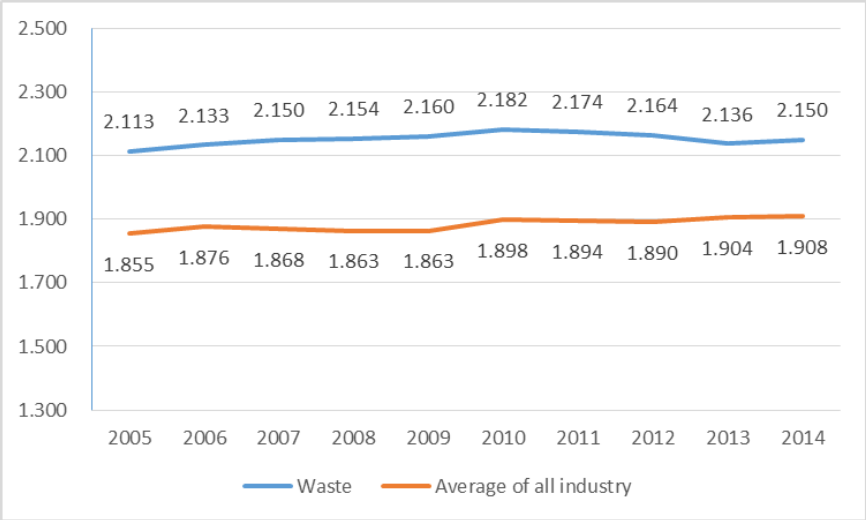

Figure 18. Output multipliers of waste industry

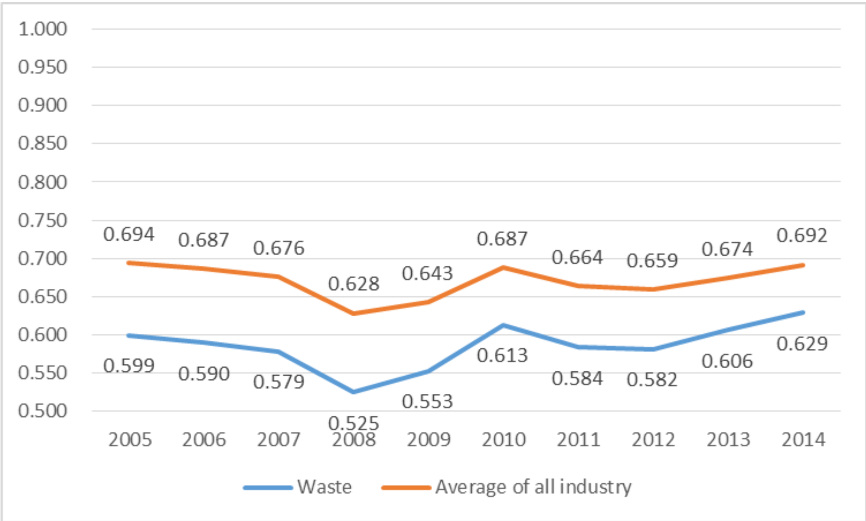

Figure 19. Value-added multiplier of waste industry

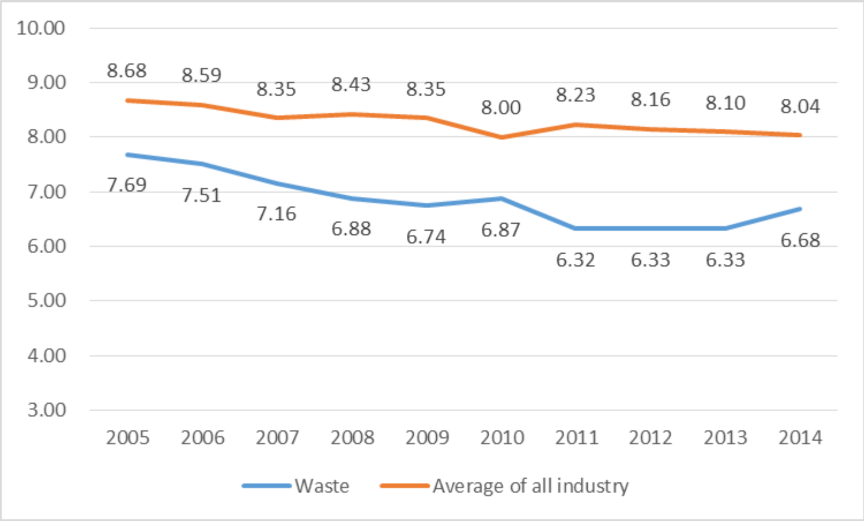

Figure 20. Employment multiplier of fuel cells industry

6) Biogas

The Biogas industry has higher output multipliers than the average of all industries. In 2014, the output multiplier of the Biogas industry is 2.296, which is about 0.095 higher than the output multiplier (1.908) of the average of all industry. The production inducement effect of the biogas industry seems to be related to the general purpose machinery industry. Looking at the trends for 2005 and 2014, the output multipliers of the biogas industry are also increasing, similar to the increasing output multiplier of the average of all industries since 2011.

In 2014, the value-added multiplier of the Biogas industry was 0.685, which was only 0.007 lower than the value added multiplier of 0.692 in the average of all industry, and the difference between the value added multiplier of the average of all industries is. This tendency shows that the contribution of the Biogas industry to the increase in domestic income is increasing at a faster rate than that of other industries.

Employment multipliers in the biogas industry were lower than the employment multipliers in the average of all industries. In 2005, the employment multiplier of the biogas industry was 8.29 person/billion won and the employment multiplier of the average of all industry was 8.68 person/billion won, however in 2014, as the difference increases, the employment multiplier of the biogas industry was 6.77 person/billion won and the employment multiplier of the average of all industry was 8.04 person/billion won. The employment multiplier of the biogas was significantly lowered until 2012, and then increased again.

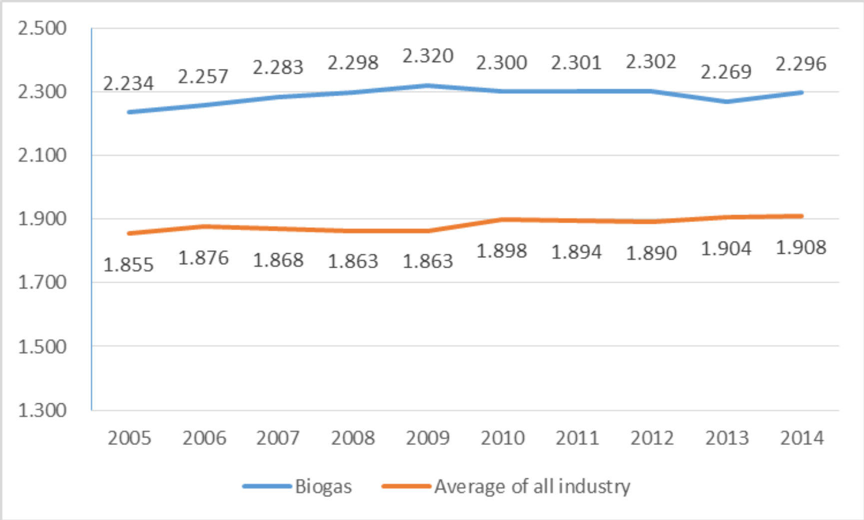

Figure 21. Output multipliers of biogas industry

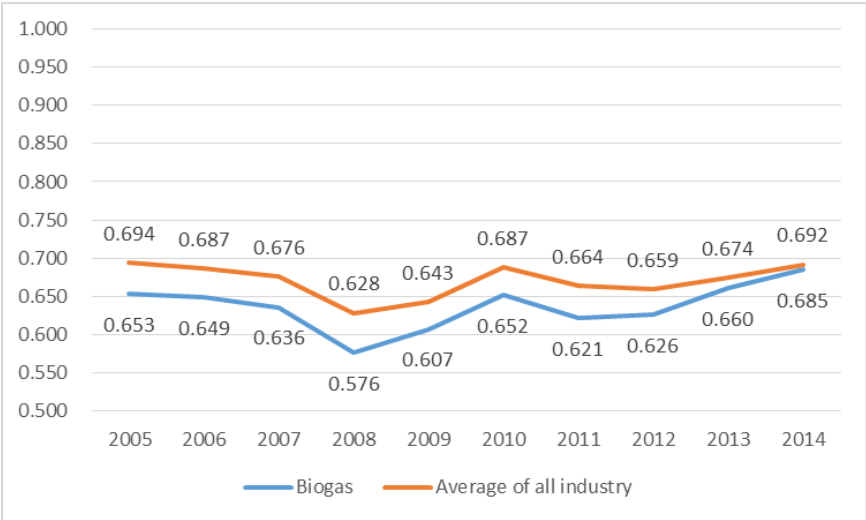

Figure 22. Value-added multiplier of biogas industry

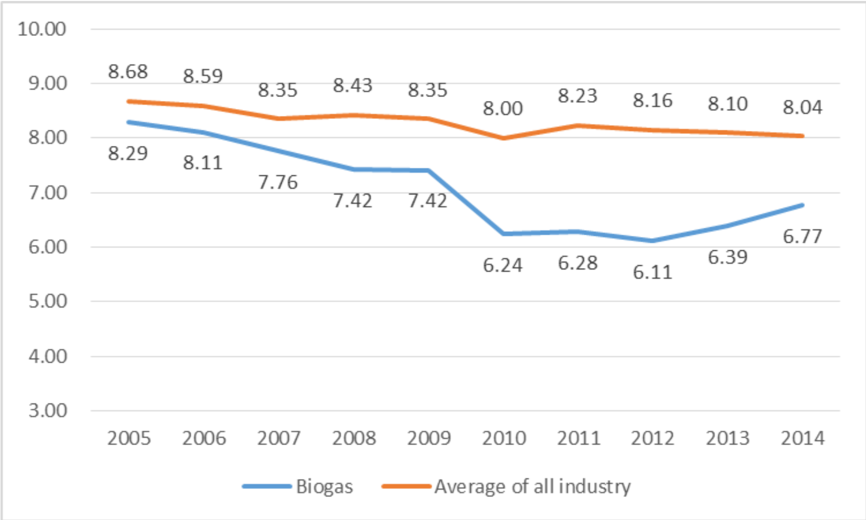

Figure 23. Employment multiplier of biogas industry

7) Biomass

The biomass industry has almost the same output multiplier as the average of all industries. In 2014, the output multiplier of the biomass industry was 1.913, which was only 0.005 higher than the output multiplier (1.908) of the average of all industry. Looking at the trends for 2005 and 2014, the output multiplier for the biomass industry was 1,876 in 2005, and the output multiplier for the average of all industry was about 1.855.

In 2014, the value-added multiplier of the biomass industry is 0.623, which is 0.069 lower than the value added multiplier of 0.692 in the average of all industry, and the difference from the value added multiplier of the average of all industry is slightly decreasing compared to 2005. This tendency can be interpreted as the degree to which the biomass industry contributes to the increase in domestic income is gradually increasing.

Employment multipliers in the biomass industry were lower than the employment multipliers in the average of all industries. In 2005, the employment multiplier of the biomass industry was 7.38 person/billion won and the employment multiplier of the average of all industry was 8.68 person/billion won, however in 2014, as the difference increases, the employment multiplier of the biomass industry was 5.84 person/billion won and the employment multiplier of the average of all industry was 8.04 person/billion won.

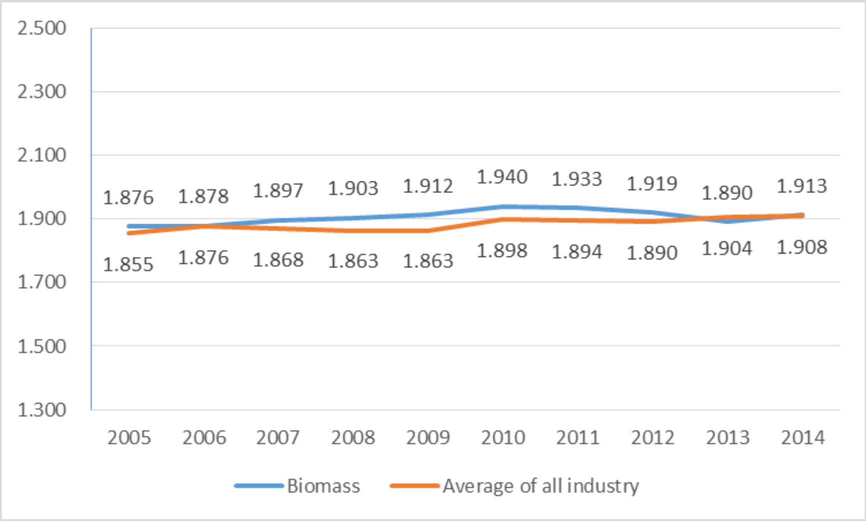

Figure 24. Output multipliers of biomass industry

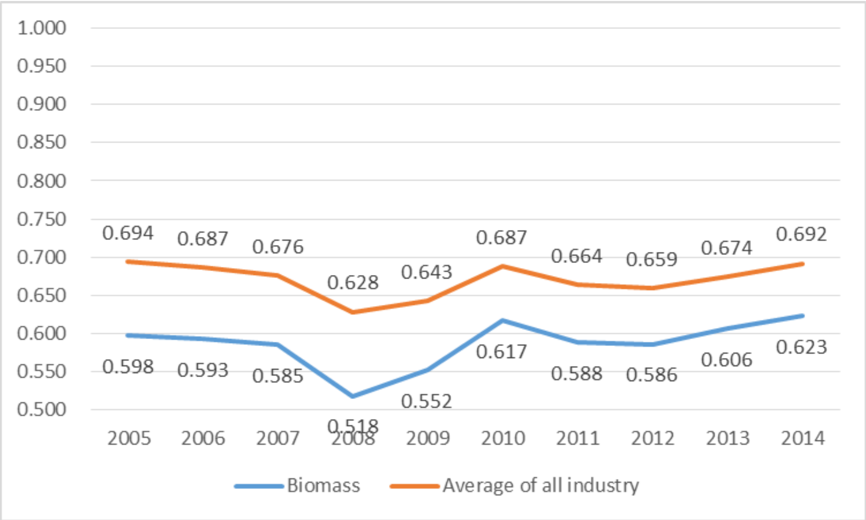

Figure 25. Value-added multiplier of biomass industry

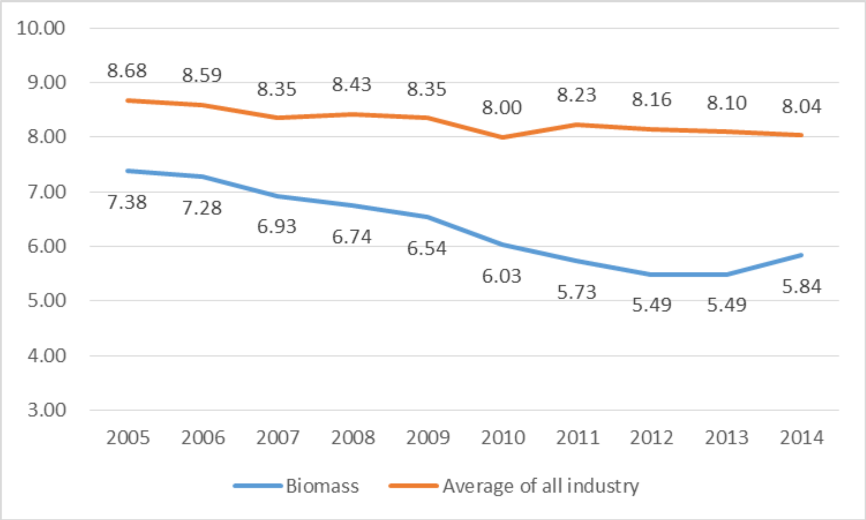

Figure 26. Employment multiplier of biomass industry

8) Geothermal

The geothermal industry has a higher output multiplier than the average of all industries. In 2014, the output multiplier of the geothermal industry is 2.239, which is about 0.331 higher than the output multiplier (1.908) of the average of all industry. The geothermal industry is considered to be the result of the fact that the ecology of the industry is related to the civil engineering and general purpose machinery industry, which has a high output multiplier. Looking at the trends for 2005 and 2014, we can see that the output multiplier of the geothermal industry has steadily increased since 2012, similar to the output multiplier of the average of all industries.

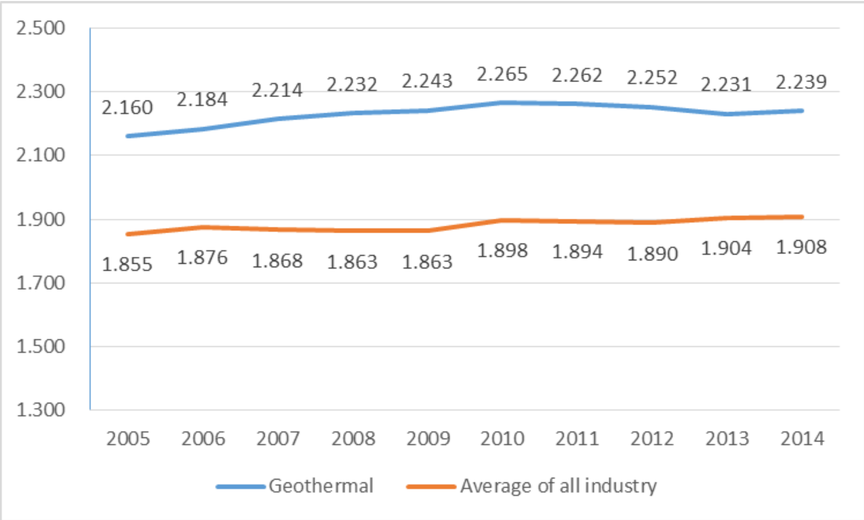

Figure 27. Output multipliers of geothermal industry

In 2014, the value-added multiplier of the geothermal industry was 0.714, which was 0.022 higher than the value added multiplier 0.692 of the average of all industry. In 2005, the value added multiplier of the geothermal industry was 0.025 But it has been reversed since 2012. This tendency can be interpreted that the degree to which the geothermal industry contributes to the increase in domestic income is gradually increasing.

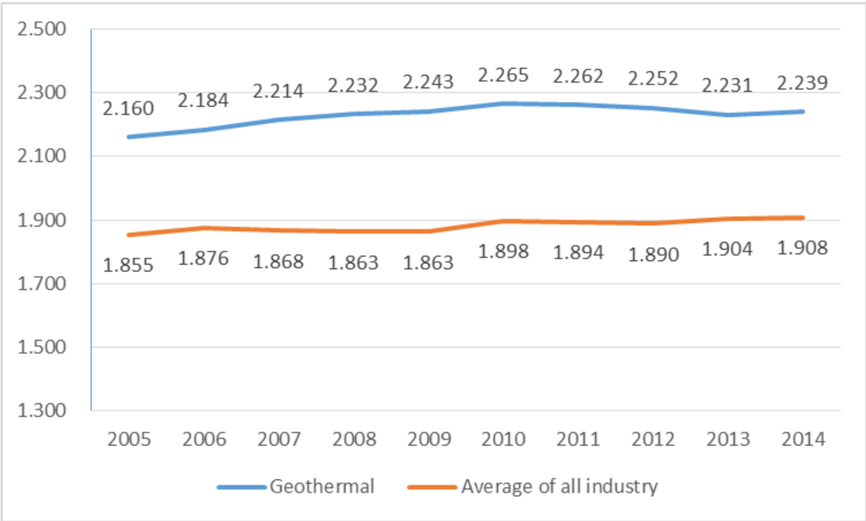

Figure 28. Value-added multiplier of geothermal industry

Employment multipliers of the geothermal industry were similar to the employment multipliers of the average of all industries. In 2005, the employment multiplier of the geothermal industry was 9.23 person/billion won and the employment multiplier of the average of all industry was 8.68 person/billion won, however in 2014, the employment multiplier of the geothermal industry was 8.04

person/billion won and the employment multiplier of the average of all industry was 8.02 person/billion won.

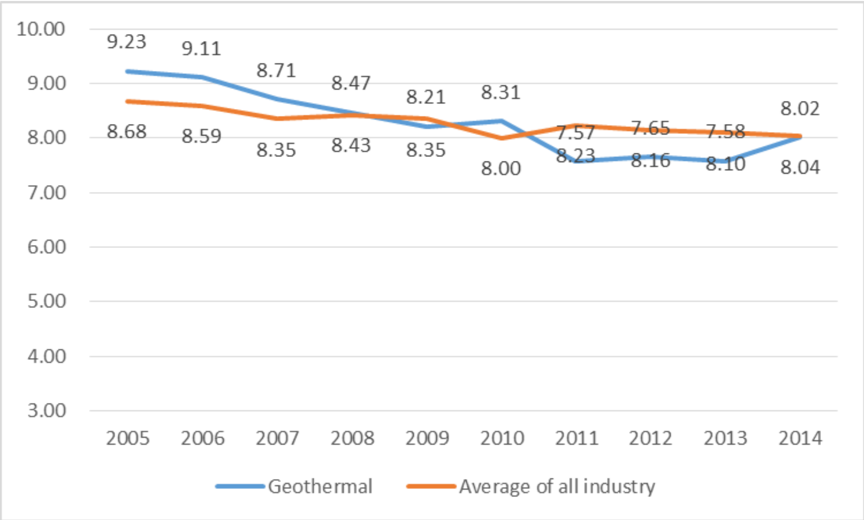

Figure 29. Employment multiplier of geothermal industry

9) Biofuel

The biofuel industry has an output multiplier similar to the average of all industries. In 2014, the output multiplier of the biofuel industry is 1.914, which is about 0.092 higher than the output multiplier (1.908) of the average of all industry. The output multiplier of the biofuel industry is considered to reflect the nature of the crop industry and other chemical products industries. Looking at the trends for 2005 and 2014, the output multiplier of the biofuel industry since 2012 was higher than the output multiplier of the average of all industry until 2009, but this trend has been reversed since 2010.

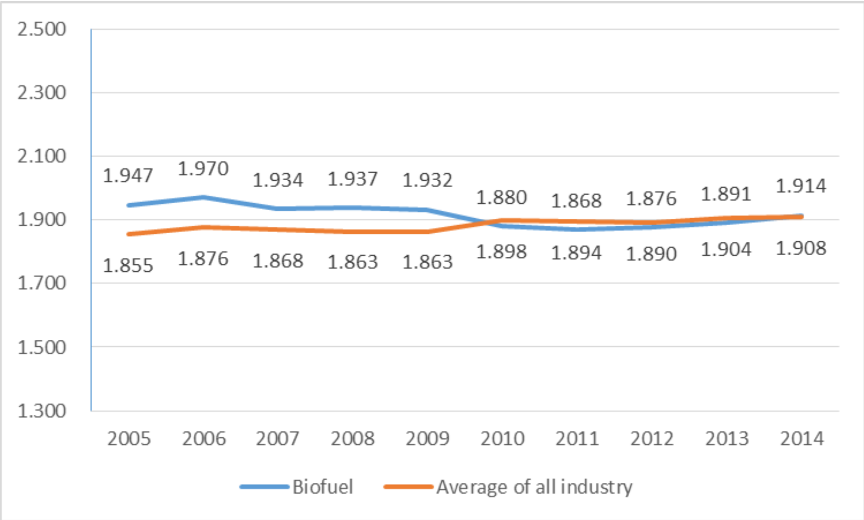

Figure 30. Output multipliers of biofuel industry

In 2014, the value-added multiplier of the biofuel industry was 0.739, which was 0.047 higher than the value added multiplier of 0.692 of the average of all industry. In 2005, the value added multiplier of the biofuel industry in the biofuel industry was 0.035 days However, this difference can be confirmed a little.

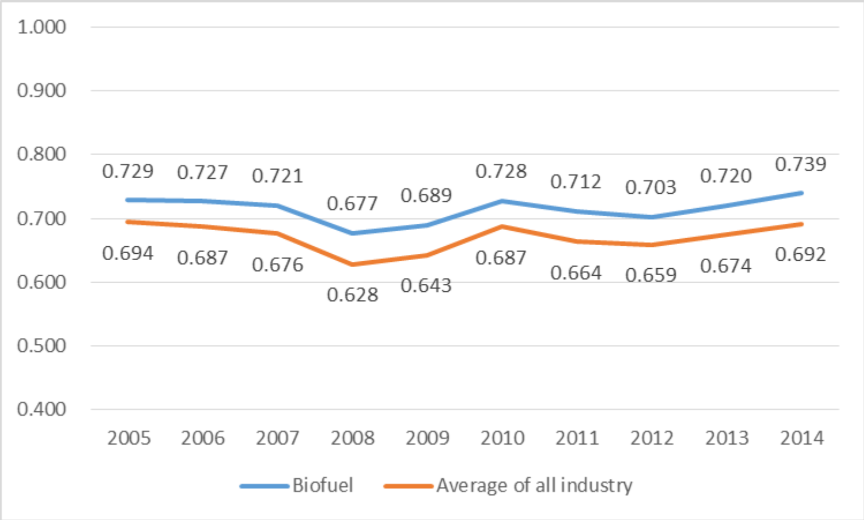

Figure 31. Value-added multiplier of biofuel industry

Employment multipliers in the biofuel industry were lower than the employment multipliers in the average of all industries. In 2005, the employment multiplier of the biofuel industry was 6.59 person/billion won and the employment multiplier of the average of all industry was 8.68 person/billion won, however in 2014, as the difference increases, the employment multiplier of the biofuel industry was 5.56 person/billion won and the employment multiplier of the average of all industry was

8.04 person/billion won.

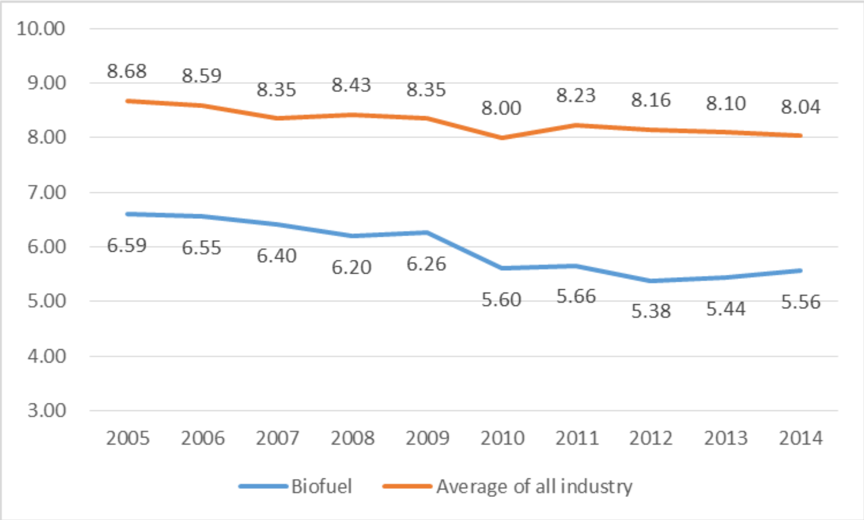

Figure 32. Employment multiplier of biofuel industry

10) Solar thermal

The solar thermal industry has higher output multipliers than the average of all industries. In 2014, the output multiplier of the solar thermal industry is 2.088, which is about 0.180 higher than the output multiplier (1.908) of the average of all industry. In the solar thermal industry, the ecology of the industry is largely related to the basic chemical industry and the precision appliance industry, and it is considered to reflect the nature of these related industries. Looking at the trends for 2005 and 2014, we see that the output multiplier of the average of all industry has increased since 2011, and that the difference from the output multiplier of the solar thermal industry is decreasing until 2013.

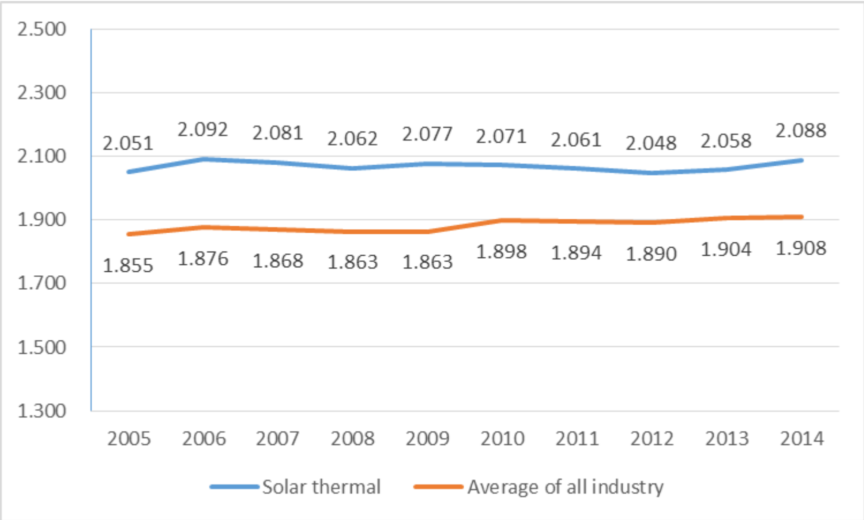

Figure 33. Output multipliers of solar thermal industry

In 2014, the value-added multiplier of the solar thermal industry was 0.539, which was 0.153 lower than the value added multiplier of 0.692 in the average of all industry. The trend since 2005 was similar to the average of all industries.

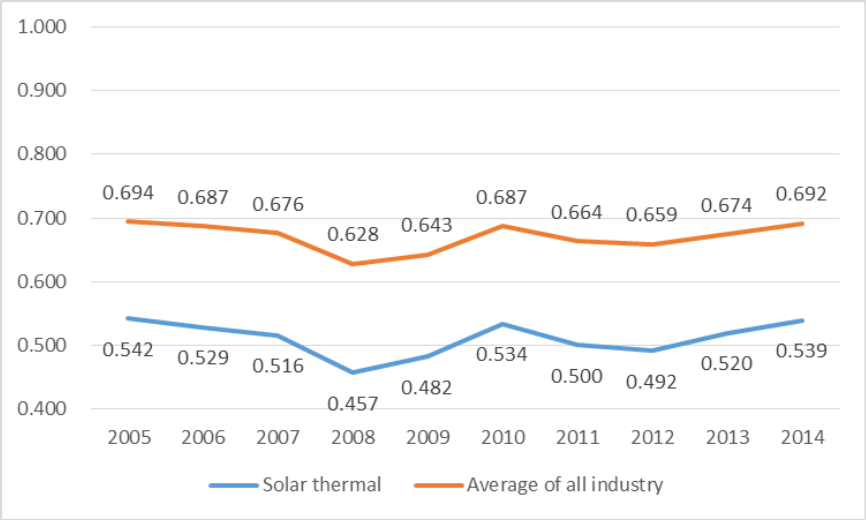

Figure 34. Value-added multiplier of solar thermal industry

Employment multipliers in the solar thermal industry were lower than the employment multipliers in the average of all industries. In 2005, the employment multiplier of the solar thermal industry was 6.18 person/billion won and the employment multiplier of the average of all industry was 8.68 person/billion won, however in 2014, as the difference increases, the employment multiplier of the solar thermal industry was 4.96 person/billion won and the employment multiplier of the average of all industry was 8.04 person/billion won. In other words, the employment inducement effect of the solar thermal industry is decreasing faster than the employment inducement effect of the average of all industry.

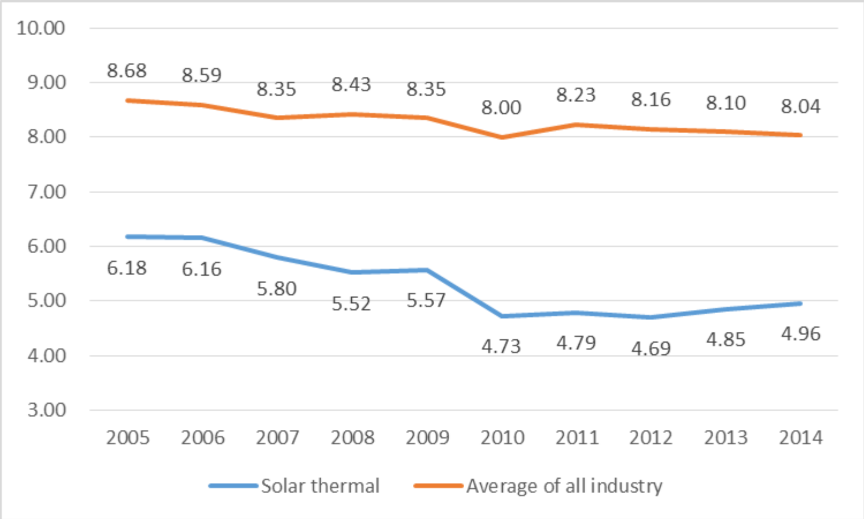

Figure 35. Employment multiplier of solar thermal industry

3.4.3.2. Intersectoral linkage

1) Index of the Power of Dispersion (IPD) and Index of the Sensitivity of Dispersion (ISD)

Table 19 shows the results of the analysis of Index of the Power of Dispersion (IPD) for each renewable energy source. As described in Section 3.3.2, the IPD indicates the backward linkage of the industry, which is normalized to 1, and if it is higher than 1, the IPD has a higher backward linkage than the industry average.

Firstly, backward linkage of the renewable energy industry is generally in the process of decreasing backward linkages although there is a difference in size between renewable energy sources. This reflects the tendency that Korea's interindustry linkage structure is gradually shifting from the manufacturing center to the service center, while the backward linkage of manufacturing industries is gradually decreasing. Between 2008 and 2010, the backward linkage is showing a slight increase overall, as it is due to the increase in the proportion of intermediate inputs, due to the decrease in the value added due to the global economic crisis rather than the linkage between industries. Can be. As of 2014, backward linkages in all energy sources were higher than the average for all industries, but in the biofuel industry, the backward linkage between 2010 and 2013 was lower than the average for all industries.

Table 19. Index of the Power of Dispersion of the renewable energy industry

	Photovoltaic	Wind	Fuel cell	micro-hydro	Waste
2005	1.075	1.221	1.123	1.167	1.140
2006	1.083	1.221	1.118	1.176	1.137
2007	1.086	1.235	1.128	1.190	1.151
2008	1.100	1.244	1.126	1.191	1.156
2009	1.115	1.253	1.128	1.192	1.153
2010	1.097	1.210	1.123	1.159	1.149
2011	1.081	1.210	1.110	1.153	1.148
2012	1.072	1.209	1.106	1.143	1.145
2013	1.052	1.192	1.088	1.143	1.122
2014	1.049	1.201	1.102	1.154	1.126
	Biogas	Biomass	Geothermal	Biofuel	Solar thermal
2005	1.205	1.012	1.165	1.050	1.106
2006	1.203	1.001	1.164	1.050	1.115
2007	1.222	1.015	1.186	1.036	1.114
2008	1.233	1.021	1.198	1.040	1.107
2009	1.238	1.020	1.197	1.031	1.109
2010	1.212	1.022	1.193	0.991	1.091
2011	1.215	1.020	1.194	0.986	1.088
2012	1.218	1.016	1.192	0.993	1.084
2013	1.191	0.992	1.171	0.993	1.081
2014	1.203	1.002	1.173	1.003	1.094

Table 20 shows the index of the sensitivity of dispersion (ISD). The results of this study are as follows. As described in Section 3.3.2, the ISD represents the forward linkage, ie, the impact on the industries demanding the industry. Normalizing to 1, the ISD has a forward linkage higher than the industry average. However, the forward linkage of the renewable energy industry should be the new renewable energy generation system, but this study evaluates the forward linkage of the element industry of the renewable energy industry. Therefore, the meaning of forward linkage is somewhat discolored. Nonetheless, forward linkage is a positive indicator because the high industry can be evaluated as having an increasing chain effect with other industries in the economy, and the industrial base is formed.

Looking at the overall forward linkage of the renewable energy industry, we can observe that forward linkage is on the rise, though it varies from circle to circle. The forward linkage of the wind, fuel cell, micro hydro, biogas, biomass and geothermal industries is on the rise, the forward linkage of the biofuel and solar thermal industries is somewhat reduced, and the photovoltaic and waste industries seem to be repeating the increase and decrease. As of 2014, for all renewable energy industries except geothermal, forward linkages were higher than average for all industries.

Table 20. Index of the Sensitivity of Dispersion of the renewable energy industry

	Photovoltaic	Wind	Fuel cell	micro-hydro	Waste
2005	1.112	1.289	1.184	0.984	1.227
2006	1.101	1.312	1.196	0.998	1.238
2007	1.101	1.319	1.205	1.004	1.242
2008	1.099	1.300	1.171	0.977	1.214
2009	1.118	1.325	1.191	0.994	1.227
2010	1.182	1.562	1.331	1.132	1.307
2011	1.147	1.533	1.297	1.116	1.275
2012	1.136	1.546	1.272	1.111	1.264
2013	1.096	1.480	1.176	1.053	1.160
2014	1.109	1.517	1.197	1.072	1.155
	Biogas	Biomass	Geothermal	Biofuel	Solar thermal
2005	1.253	0.972	0.937	1.117	1.549
2006	1.273	0.986	0.948	1.131	1.523
2007	1.282	0.995	0.956	1.099	1.528
2008	1.242	0.982	0.910	1.073	1.589
2009	1.273	0.986	0.932	1.059	1.605
2010	1.488	1.097	1.046	1.039	1.583
2011	1.458	1.093	1.026	1.041	1.574
2012	1.470	1.113	1.022	1.038	1.561
2013	1.377	1.052	0.937	1.019	1.484
2014	1.406	1.052	0.950	1.031	1.415

Changes in IPD and ISD are the two major changes in the IPD and ISD, which have been calculated through the relative size of the Output multiplier, the right upward trend in the graph, ie, the higher the IPD and ISD signifies the greater influence of the corresponding industry on the industrial ecosystem. In the first quadrant, industries with high backward linkage and forward linkage, industries with low backward linkage and low forward linkage industries in the second quadrant, industries with low backward linkage and forward linkage in the third quadrant, Industries in the fourth quadrant can be seen as high forward linkage but low backward linkage. Therefore, if the industry PSD and ISD are all in the first quadrant, the ecology of the industry is best established. Especially, if the PSD and ISD are located on the right side, this tendency is high.

The IPD value and the ISD value indicate that the renewable energy industry in Korea is generally well organized. Compared with 2005, all industries except the geothermal industry moved to the first quadrant, but the geothermal industry was classified as the industry with a high IPD value but a somewhat lower ISD.

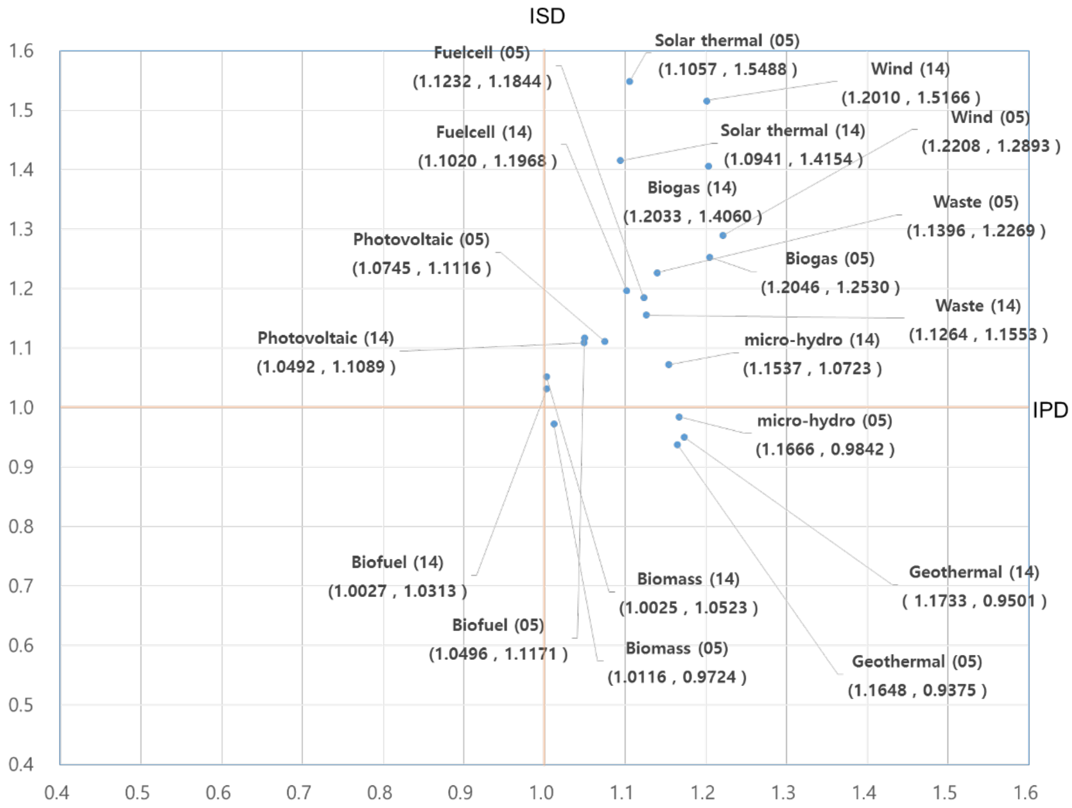

Figure 36. IPD and ISD of the renewable energy industry

2) Output-to-final demand elasticity

This chapter presents the output-to-demand elasticity of the renewable energy industry. Output-to-demand elasticity represents the increase in production of the entire industry when demand for that industry increases by 1%. While traditional ISD and IPD have a unit effect on the same investment, output-to-demand elasticity has an effect per unit of%. The input-output analysis under the Leontief model does not assume capacity constraints. That is, if intentional demand can be generated, the supply can be increased indefinitely, and this effect is calculated by multiplier analysis. However, if the domestic market of the industry is small, the effect of the investment will not occur indefinitely, and the short-term effect will be limited. Therefore, if the output-to-demand elasticity is used, the size of the industry is taken into consideration. Also, according to Perroux (1955), as a prerequisite of the propulsive industry, it is said that the most important conditions for forming a growth pole of the economy are as follows. First, the connection between existing industries and second, the scale of industry is important. Therefore, the concept of output-to-demand elasticity is more consistent with the definition of propulsive industry.

Table 21 shows the results of backward linkage analysis using output-to-final demand elasticity for each renewable energy source. The output-to-final demand elasticity is calculated by weighting the industrial scale on the Leontief inverse matrix to assess the potential of the industry. Therefore, the backward linkage (BL) value and the forward linkage (FL) value obtained by using the output-to-final demand elasticity can not be directly analyzed like IPD or ISD. However, when comparing this value with IPD and ISD, You can compare the potential of the industry when it is considered and when it is not.

First, the BL of the renewable energy industry is as follows. In the case of IPD alone, the BL value of the renewable energy industry showed a little decrease with time, but the BL value using output-to-final demand elasticity was rather increased. In other words, even if the linkage of the urea industry is relatively stagnant or weak for each renewable energy source, the size of the industry itself is growing. Therefore, considering the importance of industry linkage in industrial investment, but also the scale, it is considered that the potential of the renewable energy industry is gradually increasing. In order to compare the size of the BLs by the year of 2014, we used photovoltaic> geothermal> Fuel cell> waste> biofuel> biogas> micro hydro> biomass> wind> solar thermal.

Table 21. Backward linkage in output-to-final demand elasticity

	Photovoltaic	Wind	Fuel cell	Micro hydro	Waste
2005	0.0389	0.0144	0.0234	0.0212	0.0283
2006	0.0400	0.0150	0.0238	0.0213	0.0281
2007	0.0400	0.0163	0.0250	0.0225	0.0299
2008	0.0405	0.0184	0.0270	0.0240	0.0323
2009	0.0449	0.0181	0.0286	0.0243	0.0329
2010	0.0479	0.0170	0.0293	0.0229	0.0312
2011	0.0481	0.0186	0.0309	0.0235	0.0314
2012	0.0444	0.0207	0.0319	0.0244	0.0318
2013	0.0427	0.0198	0.0320	0.0244	0.0317
2014	0.0390	0.0192	0.0295	0.0231	0.0294
	Biogas	Biomass	Geothermal	Biofuel	Solar thermal
2005	0.0203	0.0213	0.0348	0.0252	0.0143
2006	0.0206	0.0212	0.0345	0.0255	0.0142
2007	0.0225	0.0226	0.0365	0.0254	0.0150
2008	0.0251	0.0245	0.0390	0.0245	0.0173
2009	0.0247	0.0251	0.0410	0.0228	0.0129
2010	0.0226	0.0230	0.0369	0.0241	0.0172
2011	0.0240	0.0231	0.0360	0.0254	0.0194
2012	0.0260	0.0239	0.0360	0.0260	0.0188
2013	0.0254	0.0241	0.0360	0.0257	0.0179
2014	0.0244	0.0225	0.0331	0.0259	0.0179

Table 22 shows the results of FL analysis using output-to-final demand elasticity for each renewable energy source. As with the BL, the FL using the output-to-final demand elasticity of the renewable energy industry tended to increase as a whole. In the previous section, it was confirmed that the ISD value of the renewable energy industry is increasing. However, the FL of biofuel and geothermal industries was rather stagnant.

In comparison with the size of FL by 2014, photovoltaic> fuel cell> waste> biogas> geothermal> biofuel> solar thermal> wind> biomass> micro hydro. However, in the case of BL and FL using output-to-final demand elasticity, the variation of the value is relatively large and it is considered that caution should be taken when interpreting it. In the photovoltaic industry, BL and FL, which are evaluated as IPD and ISD, are low in renewable energy, but it is noteworthy that they are rated to have the highest BL and FL in terms of industry size. In fact, the photovoltaic industry accounts for half of the sales of the renewable energy industry in Korea, and it has a big market worldwide. Thus, the results of using output-to-final demand elasticity are merely demonstrating that the results of IPD and ISD can be complemented by considering the linkage of the industry.

Table 22. Forward linkage in output-to-final demand elasticity

	Photovoltaic	Wind	Fuel cell	Micro hydro	Waste
2005	0.0324	0.0146	0.0226	0.0166	0.0241
2006	0.0324	0.0155	0.0231	0.0168	0.0244
2007	0.0325	0.0168	0.0243	0.0178	0.0260
2008	0.0325	0.0185	0.0255	0.0185	0.0276
2009	0.0350	0.0184	0.0268	0.0189	0.0269
2010	0.0456	0.0208	0.0327	0.0204	0.0298
2011	0.0477	0.0224	0.0348	0.0212	0.0307
2012	0.0444	0.0254	0.0356	0.0226	0.0317
2013	0.0426	0.0229	0.0340	0.0213	0.0296
2014	0.0405	0.0227	0.0318	0.0204	0.0276
	Biogas	Biomass	Geothermal	Biofuel	Solar thermal
2005	0.0202	0.0179	0.0250	0.0245	0.0192
2006	0.0209	0.0181	0.0250	0.0251	0.0187
2007	0.0225	0.0192	0.0264	0.0249	0.0202
2008	0.0238	0.0198	0.0270	0.0230	0.0258
2009	0.0240	0.0205	0.0284	0.0215	0.0170
2010	0.0259	0.0213	0.0284	0.0223	0.0267
2011	0.0270	0.0215	0.0281	0.0234	0.0305
2012	0.0296	0.0228	0.0290	0.0236	0.0290
2013	0.0270	0.0217	0.0274	0.0235	0.0257
2014	0.0262	0.0204	0.0256	0.0246	0.0243

Output-to-final demand elasticity is used to compute BL and FL. First, comparing the change trends for each energy source, it can be seen that BL and FL values of all renewable energy sources except geothermal are increasing. This indicates that the potential of the renewable energy industry in Korea is gradually increasing when evaluated based on the urea industry. It is also noteworthy that the potential of the wind can be evaluated to the greatest when evaluated using IPD and ISD, but the potential of the photovoltaic industry is most significant when evaluated using output-to-final demand elasticity. In the solar thermal and wind industries, the results of IPD and ISD and output-to-final demand elasticity are compared to show that the results of IPD and ISD have somewhat overestimated the potential of the industry.

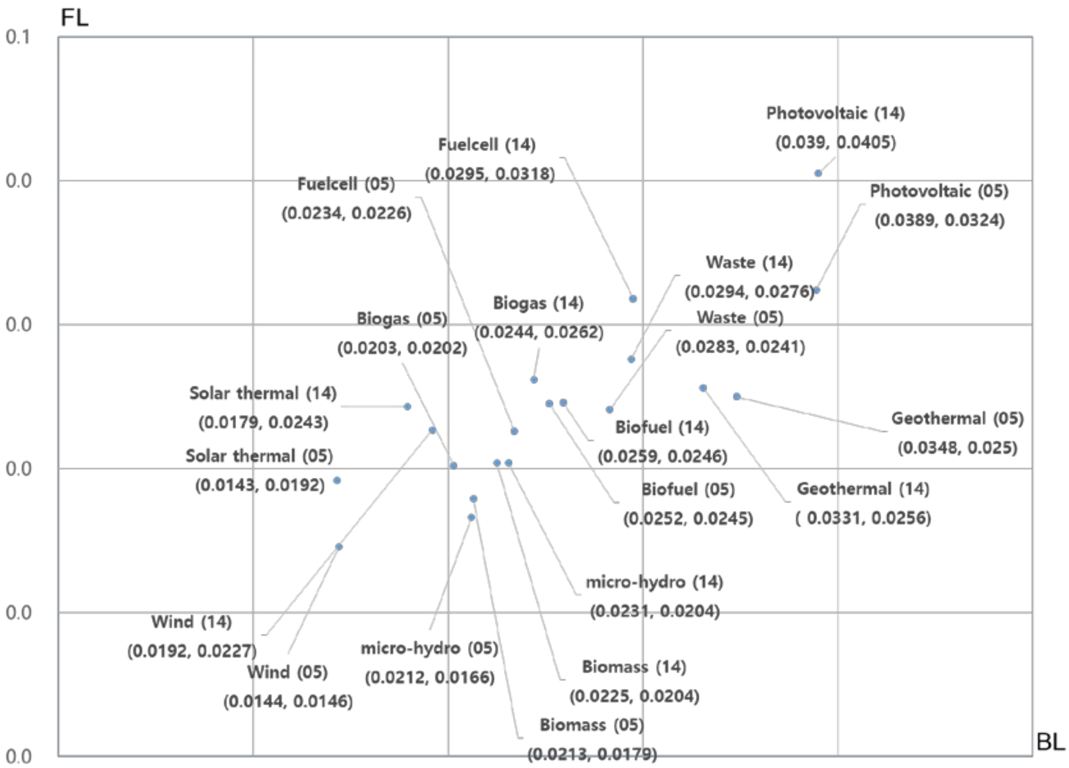

Figure 37. Bl and Fl of renewable energy technology based on output-to-demand elasticity

3.4.3.3. Economic Impacts of renewable energy industry in Korea

In this chapter, we will examine how the total amount of ripple effects of Korea's renewable energy industry has increased by using the unit-level ripple effects of the renewable industry industry so far. The Korean renewable energy industry is a new growth engine that will lead the future economic development, and the government continues to invest steadily, and the industry scale has also increased rapidly. Table 23 shows the increase in sales of the Korean renewable energy industry during the analysis period 2005-2014.

Table 23. Gross output of renewable energy industry in Korea

(unit: Korea billion won)

	Photo -voltaic	Wind	Bio-energy	Solar Thermal	Geo-thermal	Fuel cell
2005	66	195	1.4	14	4	0.5
2006	166	462	70	17	7	3
2007	441	619	136	24	11	3
2008	1577	1293	311	33	20	34
2009	2719	1073	499	62	33	78
2010	5859	972	602	65	37	128
2011	7420	1008	745	36	43	105
2012	4208	1276	813	13	38	117
2013	5159	1002	973	15	91	275
2014	4330.2	909.9	1105.5	321	108.3	228.4

It is expected that the total amount of economic impacts of the Korean renewable energy industry will increase due to the increase in sales, and the total amount of production inducement, value added inducement and employment inducement caused by this increase is shown in Table 24 ~ Table 26. However, the energy source of this statistic is limited. In the case of Bioenergy, specific energy sources (Bio-fuel, Biogas, Biomass, etc.) can not be distinguished. Therefore, this chapter only shows the effects of photovoltaic, wind, solar thermal, and geothermal fuel cell industries. It should also be noted that this statistic includes sales from overseas factories, which can be separated by 2014, but not by 2013, so that sales are mixed.

Table 24. Output inducement of renewable energy industry in Korea

	Photovoltaic	Wind	Solar Thermal	Geothermal	Fuel cell
2005	131.5	441.5	28.7	8.6	1.0
2006	337.3	1058.0	35.6	15.3	6.3
2007	894.3	1428.0	49.9	24.4	6.3
2008	3232.9	2995.9	68.0	44.6	71.4
2009	5677.3	2519.4	128.8	74.0	164.8
2010	12204.3	2232.7	134.6	83.8	272.9
2011	15188.7	2309.3	74.2	97.3	220.8
2012	8521.2	2915.7	26.6	85.6	244.5
2013	10338.6	2274.5	30.9	203.0	569.8
2014	8669.1	2085.5	670.2	242.5	480.3

Table 25. Vaule-added inducement of renewable energy industry in Korea

	Photovoltaic	Wind	Solar Thermal	Geothermal	Fuel cell
2005	40.1	131.2	7.6	2.7	0.3
2006	99.6	307.2	9.0	4.7	1.7
2007	257.5	401.1	12.4	7.2	1.7
2008	831.1	755.1	15.1	12.2	17.8
2009	1487.3	661.0	29.9	20.9	42.7
2010	3533.0	629.9	34.7	25.5	76.4
2011	4199.7	620.9	18.0	28.3	58.9
2012	2390.1	791.1	6.4	25.2	65.5
2013	3018.0	659.3	7.8	62.6	161.7
2014	2637.1	620.6	173.0	77.3	140.0

Table 26. Employment inducement of renewable energy industry in Korea

	Photovoltaic	Wind	Solar Thermal	Geothermal	Fuel cell
2005	499.6	1692.6	86.5	36.9	3.7
2006	1251.6	3936.2	104.7	63.8	21.1
2007	3192.8	5057.2	139.2	95.8	20.1
2008	11023.2	10020.8	182.2	169.4	217.6
2009	18462.0	8369.4	345.3	270.9	489.8
2010	40309.9	5997.2	307.5	307.5	724.5
2011	44520.0	6320.2	172.4	325.5	573.3
2012	25584.6	7719.8	61.0	290.7	636.5
2013	30077.0	6372.7	72.8	689.8	1551.0
2014	26414.2	6050.8	1592.2	868.6	1384.1

3.5 Conclusion and discussion

In this chapter, we analyzed the economic externalities of the renewable energy industry and resource development industry using input-output analysis. The analysis results are summarized as follows.

First, when the output multiplier is judged, the economic impact of the renewable energy industry in Korea is higher than the average of all industries, and the economic impact of the resource development industry is rather low. In particular, the output multiplier of the renewable energy industry is gradually increasing, and this tendency is expected to be further strengthened in the future. However, considering that the input-output analysis aims to analyze the short-term effects and that the resource development industry is carried out with a longer term goal than the short term, it can not said that the resource development industry has lower economic externalities than the renewable energy industry. These comparisons will require further analysis through other methodologies in the future.

Second, from the point of view of the value added multiplier, the renewable energy industry has a somewhat lower value added effect than the average of all industries, and the resource development industry brings high value added. However, the value added of renewable energy industries is gradually increasing, though it is different in each country.

Third, from the viewpoint of employment multiplier, the renewable energy industry and the resource development industry have a somewhat lower employment creation effect than the average of all industry. In particular, the resource development industry is characterized by capital intensive nature, and it is believed that the employment creation is especially low because the industrial ecology is not established yet in Korea. In addition, Korea's employment structure is shifting from the manufacturing-oriented to the service-oriented, and if the related service sector is fostered in the renewable energy and resource development industries, it will contribute to employment creation.

Fourth, in terms of backward linkage and forward linkage, the renewable energy industry is one of the industries with relatively good links with other industries in Korea. In addition, when the output-to-final demand elasticity of the inter-industry linkage is calculated considering the size of the industry, it can be seen that the results of the evaluation are different from each other. Especially, the potential of the solar industry is appreciated more. However, as mentioned above, the values of BL and FL using output-to-final demand elasticity fluctuate greatly, and there are not many cases to be used. Therefore, linkage evaluation using IPD and ISD and linkage evaluation using output-to-final demand elasticity can be complementary to each other in empirical analysis.

However, the input-output analysis is limited in that it is suitable for estimating short-term economic impacts. Therefore, this point should be kept in mind when interpreting the results, especially considering that the resource development industry is invested in a long-term goal, the evaluation results in this study may be underestimated somewhat. It is also reasonable that the growth potential of the industry under the open economy should be compared with other countries in the global market, but this is beyond the scope of this study and will be left for further study.

In addition to the results of the present study, the following policy implications can be considered. First, since the economic importance of the renewable energy industry is increasing, it can gather momentum if it is supported by a systematic development strategy that considers the interrelationship of the renewable energy industry with directly and indirectly related industries.

In particular, the existing key industries such as construction or civil engineering have reached a level at which it is difficult for them to be maintained without a continuous creation of large-scale demand, and the need for the renewable energy industry carrying out the role of replacing existing industries is increasing since the general manufacturing industry is facing a decreasing trend of value added. Therefore, there would be a need for not only investment in the renewable energy industry but also a strategy to maximize the ripple effect of the renewable energy industry through convergence with other directly or indirectly related industries.

However, in order to prevent lowering the national employment level in the industrial revolution centered on renewable energy, investment in the renewable energy industry may have to continuously increase. Furthermore, it would be necessary to design a policy that allows the development of the renewable energy industry to lead to higher national income in the midst of the declining value added trend of most traditional industries. Especially, considering that Korea's industrial structure is in the process of moving from the manufacturing industry to the service industry (Bank of Korea, 2014a, 2014b), increased effort to promote the service sector along with production in the renewable energy sector seems necessary.

Chapter 4. Source of value-added change from renewable energy industry and resource development industry

4.1 Introduction

One of the main goals of fostering the development of the renewable energy industry is to grow the national economy. Several studies have used input-output analysis to investigate these effects in Korea using input-output models. Industry linkage analysis seeks to systematically analyze the process by which investments in one industry create income in the economy as a whole. The majority of studies have focused on the total amount of output that an industry's investment incurs throughout an economy. However, according to a study by West (1999), gross output measures are susceptible to multiple counting, as they sum all intermediate transactions throughout all stages of the production process, which leads them to substantially overstate economic activity. While output effects can provide a measure of the increase in gross sales throughout an economy following an economic stimulus, they are somewhat inaccurate as a measure of net contribution to economic activity. Recently, the preferred measure of net economic impact is value added, which is defined as wages and supplements paid to labor plus gross operating surplus plus indirect taxes less subsidies (West, 1999). The sum of value added across all industries within a country is considered to be equivalent to gross domestic product

(GDP). Therefore, value added is currently the most preferred and consistent measure of net economic activity.

In this study, we attempt to analyze the impact of the renewable energy industry in terms of value added across an entire economy, for which structural decomposition analysis (SDA) is used. SDA can be used to identify drivers of changes in variables of interest based on input-output analysis. In this study, we investigated and combined two methodologies of recent attraction among scholars to form an extended SDA model. The first is value-added decomposition, which serves to decompose sources of changes in value added rather than total output. As interest in the value added created by industries has increased in recent years, this methodology has become increasingly useful. The second methodology is RAS-decomposition. The existing SDA had certain limitations, such as the fact that it could not accommodate the systematic consideration of changes in inter-industry industries. However, Dietzenbacher (2002) developed a RAS-decomposition method applying an RAS method, which was used to create an industry association table using a non-survey or partial survey method. In this study, we use a value added RAS decomposition model that combines value added decomposition and the RAS method to systematically analyze the factors that contribute to the creation of value added across all industries in Korea.

4.2 Literature review

4.2.1 GDP and renewable energy

There is a growing interest in renewable energy as renewable energy contributes to the accumulation of national wealth. Therefore, studies on the relationship between the spread of renewable energy and GDP are increasing. Fang (2011) analyzed the relationship between China's GDP and renewable energy. The analysis shows that GDP increases by 0.12% as the consumption of renewable energy increases by 1%. Sebri and Bem-Salha (2014) analyzed the relationship between Brazilian GDP and renewable energy using ARDL and Grange causality test methods. The analysis shows that there is a positive relationship between Brazilian GDP and renewable energy consumption, and Brazilian GDP also increases as the consumption of renewable energy increases. Cho (2015) divided the relationship between renewable energy and GDP into OECD countries and non-OECD countries. In the OECD countries, the consumption of renewable energy increased as the economy growth. In non-OECD countries, the economy grew due to renewable energy, although the consumption of renewable energy increased as the economy growth. Mun et al. (2016) studied the relationship between renewable energy consumption, economic growth and carbon dioxide emissions in Malaysia. Research shows that in the long term, the increase in renewable energy consumption contributes to the increase in GDP, and in the short term, the increase in GDP contributes to the increase in renewable energy consumption. IRENA (2016) analyzed the economic benefits of increased consumption of renewable energy by employment, GDP, and other costs. By 2030, when the consumption of renewable energy is two, the global GDP In the same period.

Several studies have shown that there is a positive correlation between GDP and renewable energy consumption, as shown in the above examples. It is therefore clear that increasing renewable energy consumption will have a positive impact on economic development. However, in these studies, the relationship between consumption of renewable energy and GDP was analyzed using the econometric model using total quantity variables, so it was not possible to divide the amount of renewable energy consumption by GDP by factors. These limitations complemented by studies using input-output tables.

4.2.2 Counting Value-added

A commonly used method to measure the impact of industrial production on the other industry or economy is to measure gross output generated from the production by output multiplier. Output multipliers or the output effects in impact analyses refer to gross expenditure. However, the gross output measures are known to be vulnerable to multiple counting. This is because they aggregate all the intermediate transactions over all stages of production process (West and Walker, 1999). Consequently, they tend to overstate economic activity of industries. Therefore output effects are not a good measure of the contribution to economic activity of an industry, even though they could provide a measure of the increase or decrease in sales throughout the economy.

In recent years, value added has been used as a more appropriate measure. Value added is defined as wages and salaries and supplements paid to labor plus gross operating surplus plus indirect taxes minus subsidies (West and Walker, 1999). The sum of value added from all industry is equal to Gross Domestic Product (GDP), and it is the consistent measure of economic activity of an industry.

However the problem is that it is not easy to measure GDP from production activities. Expenditure on final goods equals the amount of value added generated during its production process (Johnson, 2014). Therefore, final expenditure could indicate the amount of value added consumed, but unfortunately the national accounts do not tell us where the value added comes from.

If we were lucky enough to have detail information about specific goods, it would be possible to decompose the value added embodied in the goods across countries by breaking them and examining their elementary parts (Linden, Kraemer, and Dedrick 2009; Debrick, Kraemer, and Linden 2010; Johnson, 2014). However, this approach is virtually impossible in practice on a product-by-product basis. Even if the company that produces the goods has all the information about the part of the product, it does not have all the information about the elemental products that the company does not produce. Thus, the following approach could be considered to estimate the total value-added that occurs in the economy from the production process.

First, we need to measure how much output from each elementary industry is needed to produce the goods consumed in a given production path. For example, how much metal and plastic are needed to produce final goods (eg, computer) consumed in Korea? In this work, we need to know not only how much metal are used, but also how much metal and plastic are used in production of those computers.

Second, we need to measure how much value added is generated in the process of production of the gross output. That is, how much value added is generated in assembling the computers? And how much value added is embodied in the metal and plastic used? In other words, we need to know the amount of value added that occurs in the every step necessary to produce the final goods.

However, the data required for this process is difficult to be individually constructed by individual researchers. Therefore, the input-output table can provide good proxy data for this analysis. The input-output table contains not only information on production process of goods and inter-industry relationships, but also information on value added at each stage of production.

4.2.3 Structural Decomposition Analysis

When trying to disaggregate the total amount of change in an economic variable between two periods, the most commonly used analysis methods are index decomposition analysis and structural decomposition analysis. The greatest difference between index decomposition analysis and structural decomposition analysis is whether or not it can reflect the relationship between each production process systematically. If we use a structural decomposition analysis that uses input-output tables as the main data, it has the advantage of knowing the amount of gross output and value added that occurs in every step necessary to produce the final goods.

Structural decomposition analysis was first attempted by Leontief (1941) and then applied to disaggregate economic development using general macroeconomic theory by Chenery (1960) and Chenery and Syrquin (1976). Syrquin (1976) decomposes the change in total output into five effects: domestic final demand change effect, export change effect, change in import coefficient for domestic final demand, change in intermediate goods import coefficient, and change in input coefficient. Skolka (1974) served as a comprehensive analysis of the SDA studies of the 1970s, and based on these researches, Rose and Chem (1991) proposed a model that decomposes energy consumption into 14 factors using two-tier KLEM (capital, labor, energy, materials) production function.

The structure decomposition method has been developed according to the development of the weight selection method. This has been studied by a number of economists along with the development of the growth factor measurement methods, including the Chenery model, the Chenery-Shishido-Watanabe model, and the Syrquin model(Kim & Ryu, 2014).

According to Miller & Blair (2009), the analysis can be summarized as follows. At the first step, the total amount of change in gross outputs between two periods can be broken down into that part associated with changes in production technology, that is change in the Leontief inverse matrix, and that part related to changes in final demand.

At the next step, the total amount of change in production technology can be broken down into a part that is related with changes in technology within each industry (changes in direct input coefficients matrix) and that part related with changes in product mix within each industry. And the change in final demand can be disaggregated further into a part that related with changes in the level of final demand and a part that associated with changes in the mix of final demand. The factors that can be decomposed using this analysis are depending on the economic values to be analyzed or the judgment of the researcher. Gross output, employment, value added and energy use are the main interests of structural decomposition analysis.

4.3 Methodology

4.3.1 Value-added Structural Decomposition Analysis

The concern on the main determinants of changes in a country's GDP over time is to decompose changes in overall GDP, i.e. GDP growth, into changes of the value added coefficients, changes in the global Leontief inverse and the three linear components just described, and changes in final demand.

If we refer to Stehrer (2013), the growth factor of gdp can be decomposed as follows: The basic assumption for this analysis is from a demand-driven input-output model with the relationship that a country's gross output equals the output in intermediates and final demand goods, i.e.

$$X = Ax + f \tag{36}$$

where **x** is a vector of gross output of each industry of dimension N×1, **A** denote the direct input coefficients matrix of dimension N×N, and **f** denote a vector of final demand of dimension Nx1(N denoting the number of industries). A rearrangement of the left and right sides of this formula yields the following equations

$$X = (I - A)^{-1} f = Lf \qquad (37)$$

where **L** is the Leontief inverse matrix. Using this equation, the level and structure of final demand determines the level of gross output in each industry. This relationship is the basis of the Input-Output analysis. Pre-multiplying this equation with a value added coefficients vector which capturing value added generated per unit of gross output for each industry transforms this into total value added created in an economy which equals its GDP.

$$VX = V\,(I - A)^{-1} f = VLf = 1f = GDP \qquad (38)$$

v denote a value added coefficients vector of dimension 1xN. The change in GDP can result from changes in the value added of a country, and it is reflected in the coefficients vector, the Leontief inverse matrix and changes in final demand vector, therefore

$$\mathrm{GDP}_t - \mathrm{GDP}_{t-1} = V_t L_t F_t - V_{t-1} L_{t-1} F_{t-1} \qquad (39)$$

This equation is the basic equation of value added structural decomposition, which shows the change in GDP between the two periods by sources of change.

4.3.2 RAS decomposition

In input-output model, technological developments interact for all sectors and induce changes in the entire direct input coefficients (Linden & Dietzenbache, 2000). The structural decomposition approach disaggregates output or value-added changes into key determinants, such as technological change (input-output structure of the economy), the change in the mix of final demand, and the change in the level of final demand. However, the technological change is no longer decomposed in the basic structural decomposition model, so that the effect of technological change could not be observed in detail. Linden & Dietzenbacher (2000) proposed the new method to decompose the technological change further.

4.3.2.1. Decomposition of structural change using RAS

Linden & Dietzenbacher (2000) proposed a new model called RAS decomposition. The model is designed to overcome the criticisms that have been raised before and allows for an economically meaningful interpretation through decomposition process. The RAS decomposition model aims at describing what actually happened in the economy or industrial relationship. RAS decomposition adds to the economic implications of RAS, and it also enables us to divide the technology change between the two points of view into the changes of demand side and supply side. The process of RAS decomposition proposed by Linden & Dietzenbacher (2000) is as follows.

Each of the n sectors (industry) in an economy (a country, region, state) uses intermediate inputs and primary factor inputs to produce goods. The composition of this mix of factors is dependent on the technology (direct input coefficient). In an input-output model, the technology is represented by the matrix A of direct input coefficients matrix,

$$\mathrm{A} = \mathrm{Z}\hat{X}^{-1} \tag{30}$$

where Z is the domestic intermediate inputs and $\hat{X}^{-1}$ is the inverse of the diagonal matrix of gross outputs. Each element of A,

$$a_{ij} = \frac{z_{ij}}{x_j} \tag{31}$$

gives the amount of input of products of sector i per unit of output of sector j (i, j = 1, . . . , n). The total amount of input in sector j of primary factor inputs can be defined as follows

$$C_j = 1 - \sum_i \ a_{ij} \tag{32}$$

With the intermediate inputs, each column of A thus represents the production technology of an industry.

Technological developments, such as innovations in production processes or price changes would induce substitution of inputs and changes in the use of inputsLinden & Dietzenbacher (2000) consider the ratio of change in a_{ij}^{1}/a_{ij}^{0} , which is the input coefficients over period 0 and period 1. For each ratio we determine $\mathrm{A} = \mathrm{Z}\hat{X}^{-1}$ the part which is caused by the "fabrication effect" in sector j, , $a_{ij} = \frac{z_{ij}}{x_j}$ the part which is caused by the "substitution effect" in sector i, affecting row i, and C_j the part that is caused by the other factors.

The fabrication effect is the result from the change in the intermediate input ratio. It is described by the multipliers s_j, by which the column j of direct input coefficient matrix A_0 is multiplied. If more gross output of sector j is produced, whereas the use of intermediate input products remains unchanged, the multiplier s_j will be smaller than 1. An example is when the economies of scale occur. That is, the total amount of output is increased by a%, but the amount of intermediate inputs is raised less than a%.

Applying the multiplier s_j imply the assumption that the composition of the intermediate input mix in industry j remains constant. Therefore, the fabrication effect means a technical change which is an increase or decrease in intermediate input. This kind of effect has not been captured from the other structural decomposition analysis, it is the core contribution of RAS decomposition.

However, we should keep in mind that many different types of technical change could occur within a sector j, even from unknown sources. This can happen especially when using the aggregation level of dataset. Therefore, the fabrication effect in sector j should be viewed as an average effect.

Meanwhile, the substitution effect is calculated by using the multiplier r_i. It is multiplied uniformly on the row i of the direct input coefficient matrix A_0. Consequently, each industry uses the same percentage more or less amount of intermediate input i.

In general, however, substitution will not be happen the simple process described above in reality. However, every type of substitution will be calculated by multiplying r_i , that is an average substitution effect uniformly. This is something the researcher should consider in interpreting the results.

In addition to fabrication effects and substitution effect, there are also many other forms of technical change, which cannot be calculated by applying a multiplier s_j or a multiplier r_i. This holds for the other technical changes that affect the composition of the intermediate input mix. This type of corrections will be denoted by the cell-specific substitutions (d_{ij}).

4.3.2.2. RAS procedure

Pioneer studies related to the estimation of Input-Output table using non-survey methods were conducted mainly in Stone (1961), Stone and Brown (1962), Cambridge University, Department of Applied Economics (1963), and Bachrach (1970). RAS is the major achievement of these researches, which first proposed by Professor R. Stone of Cambridge University in England in 1963. Originally, the methodology is called as ‘Bipropotional adjustment methods’, but the result of the input coefficient adjustment is derived from the form of RAS, which is named RAS.

In the RAS method, given the Input-Output table for the base year, the total output of each industry in the target year, the aggregate intermediate demand for each industry, and the intermediate input for each industry, the input coefficient of target year is estimated by repeatedly adjusting until the convergence to the sum of the intermediate demand of the industry and the sum of the intermediate inputs in the target year. The detailed estimation procedure of the RAS method is as follows.

First, we have the input coefficient table A (0) of the n sector for the given past year and try to update it with the input coefficient A (1) of the target year. The additional information required to carry out the RAS is the total output for each industry, the total intermediate demand for each industry, and the total interim input for each industry in the target year for preparing the input and output table. Assume that this information is given first, that is, the technical coefficient remains stable with respect to time. To test this, it is necessary to check whether this is consistent with the industry-specific intermediate demand and the industry-specific intermediate inputs. First, to see the information of the industry-specific intermediate inputs, it is necessary to check whether Equation (44) holds when Equation (43) is given.

$$\mathrm{A}(0)\hat{X}(1) = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & & a_{2n} \\ \vdots & & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \begin{bmatrix} X_1(1) & 0 & \cdots & 0 \\ 0 & X_2(1) & & 0 \\ \vdots & & \ddots & \vdots \\ 0 & 0 & \cdots & X_n(1) \end{bmatrix} \tag{33}$$

$$\begin{gathered} \left[A(0)\hat{X}(1)\right]i = U(1) \\ (i = 1 \times n\ unit\ matrix) \end{gathered} \tag{34}$$

Here, if $\left[A(0)\hat{X}(1)\right]i$ is denoted by U^1, when $\mathrm{U}^1 = U(1)$ is satisfied, the estimate of $\mathrm{Z}(1) = \mathrm{A}(1)\mathrm{X}(1)$, the inter-industry transaction matrix, has a correct row sum. But generally, $\left[\mathrm{A}(0)\hat{X}(1)\right]i = U(1)$ does not hold because there is little chance of $\mathrm{A}(0) = \mathrm{A}(1)$ being satisfied. Therefore, in order to make $\left[\mathrm{A}(0)\hat{X}(1)\right]i = U(1)$ to be hold, we use the following equation to adjust $\mathrm{A}(0)$ to the information of $\mathrm{U}(1)$.

$$\mathrm{R}(1)=\begin{bmatrix}\frac{u_1(1)}{u_1^1}\\ \frac{u_2(1)}{u_1^1}\\ \vdots\\ \frac{u_{n-1}(1)}{u_1^1}\\ \frac{u_n(1)}{u_1^1}\end{bmatrix}=\begin{bmatrix}r_1^1\\ r_2^1\\ \vdots\\ r_{n-1}^1\\ r_n^1\end{bmatrix} \tag{35}$$

$$A^1=\hat{R}(1)A(0) \tag{36}$$

where $u_i(1)$ is the ith element of $U(1)$, u_i^1 is the ith element of U^1. Then, A^1, the first estimate of $A(1)$, satisfy $[\mathrm{A}(0)\hat{X}(1)]i=U(1)$.

The next step is to satisfy the conditions of intermediate demand by industry. Given Equation (47), we need to check if Equation (48) is true.

$$A^1\hat{X}(1)=\begin{bmatrix}a_{11}^1 & a_{12}^1 & \cdots & a_{1n}^1\\ a_{21}^1 & a_{22}^1 & & a_{2n}^1\\ \vdots & & \ddots & \vdots\\ a_{n1}^1 & a_{n2}^1 & \cdots & a_{nn}^1\end{bmatrix}\begin{bmatrix}X_1(1) & 0 & \cdots & 0\\ 0 & X_2(1) & & 0\\ \vdots & & \ddots & \vdots\\ 0 & 0 & \cdots & X_n(1)\end{bmatrix} \tag{37}$$

$$[A(0)\hat{X}(1)]i'=V(1) \tag{38}$$

In the same way as above, if $[A^1\hat{X}(1)]i'$ is denoted by V^1, the column sum of the estimate of $\mathrm{Z}(1)$ has correct value when V^1=V(1). However, this is almost not possible that $[A^1\hat{X}(1)]i' = \mathrm{V}(1)$ is true, because there are few possibility of $A^1 = A(1)$. Then, we adjust A^1 based on the information of $\mathrm{V}(1)$.

$$\mathrm{S}(1) = \begin{bmatrix} \frac{v_1(1)}{v_1^1} \\ \frac{v_2(1)}{u_1^1} \\ \vdots \\ \frac{v_{n-1}(1)}{v_1^1} \\ \frac{v_n(1)}{v_1^1} \end{bmatrix} = \begin{bmatrix} s_1^1 \\ s_2^1 \\ \vdots \\ s_{n-1}^1 \\ s_n^1 \end{bmatrix} \tag{39}$$

$$A^2 = A^1\hat{S}(1) = \hat{R}(1)A(0)\hat{S}(1) \tag{40}$$

where $v_i(1)$ is the ith element of $V(1)$, v_i^1 is the ith element of V^1. Then, A^2, the second estimate of $A(1)$, satisfy $[A^1\hat{X}(1)]i' = V(1)$.

Then again, we should check if $[A^2\hat{X}(1)]i = U(1)$ is true or not. If it does not, use the following equation to adjust to the A^2 based on $U(1)$.

$$\mathrm{R}(2) = \begin{bmatrix} \dfrac{u_1(1)}{u_1^1} \\ \dfrac{u_2(1)}{u_1^1} \\ \vdots \\ \dfrac{u_{n-1}(1)}{u_1^1} \\ \dfrac{u_n(1)}{u_1^1} \end{bmatrix} = \begin{bmatrix} r_1^1 \\ r_2^1 \\ \vdots \\ r_{n-1}^1 \\ r_n^1 \end{bmatrix} \tag{41}$$

$$A^3 = \hat{R}(2)A^2 = \hat{R}(2)A^1\hat{S}(1) = \hat{R}(2)\hat{R}(1)A^0\hat{S}(1) \tag{42}$$

Then, A^3, the third estimate of $A(1)$, satisfy $\left[A^3\hat{X}(1)\right]i = U(1)$. By repeating this process, finally, we can be obtained the following equation

$$A^4 = \hat{R}(2)\hat{R}(1)A^0\hat{S}(1)\hat{S}(2)$$

$$A^5 = \hat{R}(3)\hat{R}(2)\hat{R}(1)A^0\hat{S}(1)\hat{S}(2)$$

$$A^6 = \hat{R}(3)\hat{R}(2)\hat{R}(1)A^0\hat{S}(1)\hat{S}(2)\hat{S}(3)$$

$$A^7 = \hat{R}(4)\hat{R}(3)\hat{R}(2)\hat{R}(1)A^0\hat{S}(1)\hat{S}(2)\hat{S}(3)$$

$$\vdots$$

$$\vdots$$

$$A^{2k} = [\hat{R}(K) \ldots \ldots \hat{R}(1)]A^0[\hat{S}(1) \ldots \ldots \hat{S}(K)] \tag{43}$$

This process is repeated until it meets certain criteria. The criterion used in this case is the difference of the elements of the correction factors R and S from 1. If this difference satisfies any small positive number(for example, 0.0001), it will stop the iterative process described above.

In this estimation process, it is economically interpreted as a substitution effect and a fabrication effect that the process of correction A by multiply R and S. The substitution effect is that one input replaces another input during the production process. The fabrication effect refers to a change in the proportion of value added items among the total purchase amount of one sector. Therefore, the RAS process has a logical economic basis as long as the changes in production technology are reflected in the substitution effects and fabrication effect.

The characteristics of the results obtained through the RAS method are as follows. First, it is possible to estimate the industry association table with only a small amount of information. The only information required to predict the total input coefficient by applying RAS is the total output (n), intermediate demand (n), and intermediate input amount (n) of each industry.

Second, among the input coefficient matrix, an element having a value of '0' has a value of '0' after correction. This leads to a conservative estimate of the input coefficient of the industry.

Third, the sign of the input coefficient does not change after the correction of the input coefficient matrix. The row and column correction coefficients obtained in the calculation are not negative in all industries. Therefore, no matter how many iterations are performed, the sign of the input coefficient does not change.

Fourth, the calculation process is simple and intuitive. It is easy to comprehend, and complex programming is not required in the calculation process since the calculation process is performed by simple repetition through the correction coefficient without the need of solving complex equations such as problems of nonlinear planning.

Fifth, despite the characteristics of 'fourth', the reliability of calculation results is high. Although the input coefficient matrix may not be close to the industry association table created through the measurement method, it is known that the total output change due to the production inducement coefficient or the final demand change leads to a value that is close to the actual value (Bank of Korea, 2006).

Three of the above five features, except for the last two, may be advantageous or disadvantageous in some cases. For example, after the industry has grown sufficiently and has entered the maturity stage, it has been observed that changes in production technology will be small (because the input coefficients will be stable). And also, it will be difficult to see new input sectors in the field that was not demanded in the industry before. Therefore, in this case, it is appropriate that the sign of the input coefficient is stable and the coefficient of '0' is maintained as it is. However, in the case of industries that are in the growth phase, these characteristics are likely to reduce the credibility of the results, since changes in the inputs are more likely to occur.

4.4. Empirical Analysis

4.4.1. Data

The core data used in this study is the industry association table published by the Bank of Korea for the period from 2010 to 2014. The input-output table for 2010 is the benchmark table, and the table for 2011, 2012, 2013, and 2014 is the table created by using the partial survey method and the modified RAS method.

The 'renewable energy sector' was first introduced in the 2010 industry entry table, published in 2014, the new and renewable power industry is defined as the ‘renewable energy’ sector it is one of the sub-sectors included in the ‘production, collection, and distribution of electricity’ sector. Here, the ‘production, collection, and distribution of electricity’ sector is defined as the industry that produces and supplies electricity to other industries or final sectors.

Before the empirical study, we compare the economic properties of renewable power industry with that of other power sources based on the input-output table. In 2010, the total gross output of renewable energy supplied in Korea was 626,719 million Korean won. 84.84% of that is used for intermediate demand sector and the remaining 15.16% was used for electricity consumption in the final demand sector.

The rate of intermediate input of the renewable energy sector was 73.45%, higher than that of hydroelectricity power generation (56.41%), thermal power generation (69.73%), and nuclear power generation (54.71%), but slightly lower than that of independent power generation (78.47%). The localization ratio, which is the proportion of domestic intermediary goods in intermediate input, is 95.33%, higher than that of other power sources, such as hydroelectric power generation (90.86%), thermal power generation (58.22%), nuclear power generation (69.13%), and independent power generation (55.93%). The rate of value-added input, 26.55%, is a little bit higher than that of independent power generation (21.76%), but lower than that of hydroelectric power generation (43.69%), thermal power generation (30.74%), and nuclear power generation (46.39%).

4.4.2. Results

Before showing the results of the value added RAS decomposition, the total output change and the total value added change of the renewable energy generation industry for the period 2010 to 2014 were compared to the table 27.

During the analysis period, the ratio of value added inducement to output of renewable energy generation industry increased. During the period from 2014 to 2010, the output of renewable energy generation increased by a total of 1,761,727 million Korean won, resulting in a value added of 580,454 million Korean won. This means that whenever the output of the renewable energy generation industry increases by one unit, the value added by Korea increases by 0.329 units. For reference, the value added per unit output of thermal power generation is 0.825, and the value added per unit output of nuclear power generation is 0.533, which gives higher value added than renewable energy generation. These values mean that, in order to contribute to the national economy due to the renewable energy generation industry, it is necessary to develop into a higher value-added industry in the future. However, observing this change over time, the contribution to the value added of the renewable energy industry is gradually increasing, and it is expected that the impact on the increase of the national income will be greater in the future.

Table 27. Output and VA change of renewable energy generation industry

	Output change (A)	VA change (B)	B/A
2011-2010	436,576	103,790	0.238
2012-2011	277,139	46,510	0.168
2013-2012	541,830	180,400	0.333
2014-2013	506,182	249,754	0.493
2014-2010	1,761,727	580,454	0.329

Table 28 shows the results of Value added RAS decomposition for 2010-2014. The value added of renewable energy generation in the whole period was increased by 24.37% due to increased value added input, 61.80% due to fabrication change, 0.50% due to substitution with other industries, due to cell specific change Increase of 1.46% and increase of 11.87% due to final demand change. In other words, the increase in value added caused by renewable energy generation during the period from 2014 to 2010 has the greatest effect from the increasing value of the input structure of renewable energy rather than replacing other industries. The second largest effect is the increase in value added in the industry.

Table 28. VA RAS decomposition results for 2010 to 2014

Source of change	Value (unit: million Korean won)	Ratio
VA intensity change effect	141,476	24.37%
Fabrication change effect	358,695	61.80%
Substitution effect	2,903	0.50%
Cell specific change effect	8,489	1.46%
Final demand change effect	68,891	11.87%
Total VA Change	580,454	100.00%

This is divided into the following Table 29 ~ Table 32. First, the value added induced changes during the period 2010 to 2011 are shown in table x. From 2010 to 2011, the value added of renewable energy generation increased by 103,790 million Korean won. Of these, 78.90% occurred due to the fabrication change effect, and 18.75% occurred with the final demand change effect. The VA intensity change effect during this period was analyzed to be 0, which seems to have come from the limitation that the 2011 input-output table was created using partial survey method. Therefore, interpretation of this value is necessary.

Table 29. VA RAS decomposition results for 2010 to 2011

Source of change	Value (unit: million Korean won)	Ratio
VA intensity change effect	0	0.00%
Fabrication change effect	81,887	78.90%
Substitution effect	3,208	3.09%
Cell specific change effect	-768	-0.74%
Final demand change effect	19,462	18.75%
Total	103,790	100.00%

The value added induced changes during 2011-2012 are shown in table 28. From 2011 to 2012, the value added of renewable energy generation increased by 46,510 million Korean won. Of these, 113.93% occurred due to the fabrication change effect, and 28.07% occurred due to the final demand change effect. The VA intensity change effect during this period was -37.36%, which was rather attributed to the decrease in value added. The value added due to substitution effect and cell specific effect also decreased.

Table 30. VA RAS decomposition results for 2011 to 2012

Source of change	Value (unit: million Korean won)	Ratio
VA intensity change effect	-17,374	-37.36%
Fabrication change effect	52,988	113.93%
Substitution effect	-1,667	-3.58%
Cell specific change effect	-494	-1.06%
Final demand change effect	13,057	28.07%
Total	46,510	100.00%

The value added induced changes during the period from 2012 to 2013 are shown in Table 29. From 2012 to 2013, the value added of renewable energy generation increased by 180,400 million Korean won. Of these, 66.50% occurred due to the fabrication change effect, and 28.20% occurred due to the VA intensity change effect, indicating that the value added input structure improved. Substitution effect and cell specific change effect were similar to 2.75% and 2.52%, respectively.

Table 31. VA RAS decomposition results for 2012 to 2013

Source of change	Value (unit: million Korean won)	Ratio
VA intensity change effect	50,873	28.20%
Fabrication change effect	119,970	66.50%
Substitution effect	4,953	2.75%
Cell specific change effect	4,554	2.52%
Final demand change effect	51	0.03%
Total	180,400	100.00%

The value added induced changes during the period from 2013 to 2014 are shown in table 30. From 2013 to 2014, the value added of renewable energy generation increased by 249,754 million Korean won. Of these, 41.58% occurred due to fabrication change effect, and 43.23% occurred due to VA intensity change effect, which shows that the input structure of value added improved. For the first time in this period, the VA intensity effect is the largest contributor to the value added generation, and the input of value added related to the renewable energy generation industry is increasing. The final demand change effect was also 14.54%. Cell specific change effect was 2.08% and Substitution effect was -1.44%.

Table 32. VA RAS decomposition results for 2013 to 2014

Source of change	Value (unit: million Korean won)	Ratio
VA intensity change effect	107,978	43.23%
Fabrication change effect	103,850	41.58%
Substitution effect	-3,591	-1.44%
Cell specific change effect	5,196	2.08%
Final demand change effect	36,321	14.54%
Total	249,754	100.00%

4.5. Conclusion and discussion

The results of this study are summarized as follows.

First, the contribution of renewable energy to national income is still low compared to other industries. Value-added due to the spread of renewable energy during the analysis period is about 0.329 per unit of output, which is still low compared to other energy industries. However, when we divide by year, the ratio of value added incidence is increasing gradually since 2012, and there is a possibility of growth in high value-added industries in the future.

Second, the most significant effect of the value addition due to the supply of renewable energy is the change of the structure of the renewable energy industry, with 61.60% being the largest share. The second most contributing factor is the increase in the intensity of value added, which accounts for approximately 24.37% of the effect. We conclude that adding these two effects can account for more than 85% of the value added increase in the renewable energy industry. This is because the renewable energy industry in Korea's industry linkage table now includes all 11 renewable energy sources, which can be seen as a result of changes in the composition of energy sources. Also, as renewable energy technology is at a growth stage, it can be seen that the renewable energy industry is gradually increasing in value.

According to the results of this study, the spread of renewable energy is now increasing in the direction of increasing income, although the impact on the increase of income of the country is not big compared to other industries. However, considering the industrial characteristics of the renewable energy industry, it is considered that the income increase due to the export of renewable energy facilities as well as the supply of renewable energy will be greater. However, since the renewable energy equipment industry has not yet been specified in the input-output table, this study did not consider all of them. However, considering the fact that the effects of domestic demand in the renewable energy equipment industry are considered to be included, the advantage of the industry association analysis is that it can consider all of the lower-level supply chain through inter-industry linkage. It is judged that it has been analyzed.

Based on the results of this study, suggesting the development direction of renewable energy industry for future high value value added of renewable energy industry will increase demand for renewable energy and substitute for other energy industry. As a result of the value added decomposition for the renewable energy industry, it was confirmed that the effect caused by the increase in the demand for the renewable energy industry is rather small. Although Korea's renewable energy demand is still small compared to other energy industries, it is necessary to increase the demand for renewable energy considering the tendency that the renewable energy industry is highly valued.

Chapter 5. Conclusion

This study has examined important characteristics of the propulsive industry, which are technological externality, pecuniary externality and contribution to economic growth in the case of renewable energy industry of Korea. The empirical analysis was conducted not only on the renewable energy industry but also on the resource development industry, and the comparison between these energy industries was conducted. The results of this study are summarized as follows.

1) Technological externalities of the renewable energy and resource development industries

New and renewable energy and resource development technologies play an important role in transferring knowledge to other technology fields. With the exception of technologies related to solar thermal and hydro energy, they have shown a high degree of knowledge spillover into other fields. This result implies that investment in renewable energy and resource development can effectively promote technological innovation in other fields. In addition, the technology related to each energy source is ranked in the following order of externalities based on D+R, an important measurement derived from DEMATEL, thus: photovoltaics (0.235) > resource development (0.126) > fuel cells (0.069) > biogas (0.064) > wind energy (0.052) > waste (0.048) > solid/liquid fuels (0.0460) > geothermal (0.045) > solar thermal (0.034).

To sum up, it can be concluded that investment in renewable energy technologies and resource development technologies shows relatively high technology externalities through knowledge spillover.

2) Pecuniary externalities of the new and renewable energy and resource development industries

The output multiplier, the economic impact of the new and renewable energy industries in Korea is higher than the average for all industries, while the economic impact of the resource development industry is rather low. In particular, the output multiplier of the new and renewable energy industries is gradually increasing, a tendency that is expected to be further strengthened in the future. However, considering that the input-output analysis is aimed at analyzing the short-term impacts and that the resource development industry aims at longer-term goals than the short-term, future outcomes may change.

From the value-added multiplier point of view, the new and renewable energy industry has a somewhat lower value-added effect than that shown by the average of all industries, while the resource development industry brings a high value added. However, the value added of new and renewable energy industries is gradually increasing, although it is different in each country.

In terms of employment multipliers, the renewable energy and resource development industries have a somewhat lower job creation effect than the average of all industries. In particular, the resource development industry is characterized by a capital intensive nature, and it is believed that the employment creation is especially low because the industrial ecology is not established yet in Korea.

Looking at the linkages between industries from the backward and forward (BL and FL) perspectives, the new and renewable energy industries are in the group of industries that are relatively well connected with other industries in Korea. In this study, we also studied a model to obtain BL and FL. In addition, BL and FL using output-to-final demand elasticity complemented the conventional input-output model to evaluate the potential of the propulsive industry. It is possible that this can play a role here.

3) Source of value-added change from renewable energy industry

The contribution of new and renewable energy to the increase of national income is still low compared to other industries. The value added due to the spread of renewable energy during the analysis period was about 0.329 per unit of output, which is still low compared to other energy industries. However, when we divide by year, the ratio of value-added incidence is shown to have increased gradually since 2012, and there is a possibility of growth in high value-added industries in the future. The most significant effect of value added due to the diffusion of new and renewable energy, accounting for 61.60% of this, is the change in the structure of the new and renewable energy industries. The second most important contributing factor is the increase in the intensity of value added, which accounts for approximately 24.37% of the effect. Although the demand for new renewable energy is still low compared to other energy industries. Considering that the new and renewable energy industries are highly valued, it is expected that the effect of renewable energy supply will increase in the future.

Consequently, the Korean renewable energy industry as a propulsive industry can be evaluated by summarizing the above. First, the technological externalities of renewable energy technologies are lower than those of resource development technologies, but they can lead to innovation of other technology groups when considering the entire science and technology group. Especially, In terms of technological externality, photovoltaic industry and resource development industry can be evaluated as propulsive industry.

Second, considering the economic externalities, the elementary industries in the new and renewable energy sector may have a higher output inducement effect than that of the resource development technology group, but this is insufficient in terms of value added and employment inducement. If the propulsive industry is selected based on BL and FL as proposed by Hirshman, wind industry and photovoltaic industry can be considered as propulsive industry.

Third, in relation to these externalities, the value added of Korea's renewable energy supply is rather low, but it is steadily increasing. As the contribution to national income is improving due to the improvement of production technology, it is expected that the value added will increase in the future.

This study has made the following additional contributions. First, we have suggested a method to evaluate knowledge spillover in relation to the entire technology group. The DEMATEL method used in this study was originally a decision method utilizing qualitative data, but there have been several recent attempts to introduce quantitative evaluation into it. In this study, we tried the DEMATEL method using the patent citation matrix to evaluate the technological externalities of the new and renewable energy industry.

Second, we have examined the input-output model to evaluate the potential of the industry. The input-output model is the most representative method for evaluating the propulsive industry, and many improvements have been discussed in relation to the potential assessment of the industry. In this study, we have reviewed the improvement models and analyzed the BL and FL applying output-to-demand elasticity to complement the results of conventional input-output analysis.

Third, the value-added structural decomposition analysis method for analyzing the effect of industrial growth on national income and a RAS decomposition method for more systematically analyzing the effect of production technology change. Through the value-added RAS decomposition model was specially constructed. this model, we were able to analyze the impact of fabrication change effect and substitution effect.

However, because the results of this study are limited to estimating short-term externalities, these points should be kept in mind when interpreting the results; especially considering that the resource development industry represents an investment in long-term goals, the evaluation results gained here may be somewhat underestimated. It would also be helpful to compare the growth potential of the propulsive industry in Korea with that of other countries in the global market; this is beyond the scope of this work, and will be left for further study.

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Three Essays on external economy of propulsive industry: focuses on Korean renewable energy industry

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요약 (국문초록)

본 연구에서는 한국의 재생에너지산업이 propulsive industry가 될 수 있는가를 외부성의 관점에서 검토해보았다. Propulsive industry는 높은 기술적 외부성과 금전적 외부성을 가지며, 이 외부성을 통해 타 산업의 성장을 효율적으로 선도하여 경제성장을 더 빠르게 달성할 수 있게 하는 특징이 있는 산업을 말한다. 한국의 재생에너지산업은 에너지신산업 육성의 주요 수단이며, 정부에서는 궁극적으로 미래 수출산업으로 육성시키고자 정책적 지원을 지속하고 있다. 따라서 재생에너지산업은 미래 propulsive industry의 좋은 후보군 이라고

할 수 있다. 본 연구에서는 앞서 언급한 propulsive industry의 특징에 따라 세 파트의 실증분석을 진행하였다.

첫 번째 실증분석은 재생에너지산업의 기술적 외부성의 검토이다. 기술적 외부성은 특허인용관계를 이용하여 특허 출원간의 후방연쇄와 전방연쇄 관계를 이용하여 살펴보았으며, 이를 위하여 DEMATEL 방법을 patent citation matrix에 적용하였다. Patent citation matrix는 USTPO(United States Patent and Trademark Office)의 patent citation 정보를 수집하여 작성한 the University of Amsterdam 의 Leydesdorff교수의 database를 이용하였다. 분석 결과 재생에너지 기술의 외부성은 태양광기술을 제외하면 자원개발기술보다 낮았다. 그러나 재생에너지기술과 자원개발 기술 모두 전체 과학기술혁신과정에서 혁신을 흡수 및 전달하는 역할이 크며, 특히 혁신을 전달하는 역할을 더 크게 하고 있는 것으로 나타났다.

두 번째 실증분석은 재생에너지산업의 pecuniary externality이다. 분석 방법으로는 산업연관분석을 적용하였는데, 재생에너지산업의 생산유발효과, 고용유발효과, 부가가치유발효과와 더불어. Hirschman의 제안에 따라 후방연쇄효과와 전방연쇄효과를 분석하는 지수들을 추가로 살펴보았다. 재생에너지산업의 생산유발효과는 전산업평균과 자원개발산업보다 높은 수준이었고, 부가가치유발효과는 전산업평균과 자원개발산업보다 다소 낮았다. 고용유발효과는 전산업평균보다는 낮고 자원개발산업보다는 높은 것으로 분석되었다.

또한 단위당 후방연쇄효과와 전방연쇄효과를 나타내는 영향력계수와 감응도계수를 근거로 판단할 때는 풍력산업이 잠재력이 높은 것으로 판단되었으나, 산업의 최종수요가 경제 전체 생산유발에 미치는 정도를 반영한 output-elasticity를 근거로 판단할 때는 태양광 산업의 잠재력이 높은 것으로 판단되었다.

세 번째 실증분석은 재생에너지발전의 증가가 한국의 GDP 증가에 미치는 영향 및 그 변화요인을 살펴보았다. 분석방법으로는 Structural Decomposition Analysis (SDA)의 하나인 Value added RAS decomposition 방법을 이용하였으며, 분석 Data로는 2010년에서 2014년까지의 산업연관표를 이용하였다. Value added RAS decomposition 방법을 활용하면 실제 산업활동이 GDP 분배에 미치는 요인을 분석하는 것과 더불어, 생산기술의 변화를 수요측과 공급측으로 나누어 분석할 수 있다. 2010년부터 2014년까지 한국의 재생에너지 발전의 증가가 유발하는 부가가치는 재생에너지 생산기술의 변화가 미치는 요인이 약 61.80%로 가장 컸으며, 재생에너지 생산시 투입되는 부가가치 비중의 증가요인이 그 다음으로 큰 24.37%를 차지하였다. 또한 재생에너지 발전 한 단위가 증가하는 동안 경제 전체의 부가가치는 0.329 만큼 증가하였는데, 이는 타 발전원들과 비교했을때는 아직 다소 낮은 편이었다. 그러나 연구결과를 연도별로 나누어보면 재생에너지 발전의 증가로 인한 부가가치의 비중이 증가하고 있는 것도 확인할 수 있었다.